The Karlsruhe Physics Course

for the lower secondary school

The Teacher's Manual

Note to the reader

We have chosen a *one-section-one-page* layout. The advantage is that figures, tables and equations stay where they are supposed to be. Moreover, it is easy to update the text. For reading we recommend the Adobe reader or the GoodReader.

Friedrich Herrmann

The Karlsruhe Physics Course

A Physics Text Book for the Lower Secondary School
The Teacher's Manual

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Preface to the first Edition

Mathematicians have a tradition of tending to and participating in the conceptual structures of their field. This has not been the case among physicists. At the university level, physicists have always had a tendency to push the limits of their field and to work where there are “new” things to be done, especially in the fields of elementary particle physics, astrophysics or the physics of complex systems. In the process, they tend to neglect cleaning up their own garden. New results are often simply added to the already present structures and the search for more then continues.

This is reflected in teaching. There are great similarities between a “modern” physics textbook and one written at the turn of the 19th century. They are probably too great considering that most of the physicists that have ever existed lived in the 20th century or are still alive today. The insights of 20th century physics are often treated as appendages. The books contain the old and the new but not a desirable synthesis of old and new. This is one reason why physics courses have so much trouble with the subject matter.

Work has been done at the Institute for Physics Didactics at the University in Karlsruhe toward a new arrangement of the contents of physics. The result of our work is one solution to this problem, but we do not claim it is the only one.

Professor G. Falk laid the foundation for this new structuring of physics. Under his guidance, numerous courses at the university, introductory, middle school and high school levels were developed. Many colleagues have also been involved with the development and propagation of theses courses. For this reason, it would actually be appropriate to call what will be presented here the “Falk School.”

We are presenting the Karlsruhe Physics Course for the middle school level. It was created after eight years of trials at the Public Gymnasium in Wörth am Rhein.

I am grateful to many colleagues and supporters of this project.

First and foremost I wish to thank my teacher, Professor Falk. He is responsible for the theoretical basis upon which all these courses rest. Without him, none of these courses would exist.

Another person, some of whose many ideas are contained in this book and whom I wish to thank, is Dr. G. Job of the University of Hamburg. Large parts of the thermodynamics as well as physical chemistry contained here are based upon his work.

A special thanks goes to my Ph.D students, Dr. Schmälzle, Dr. Mingirulli, and Dr. Morawietz. They performed most of the detail work and I carried out the trials in Wörth with their help.

I am very grateful to the colleagues involved in the trials being carried out on a large scale in Baden-Württemberg and in Rheinland-Pfalz. Participating in this brings them no personal advantages. They have gladly taken part and sacrificed much time for this, and their constructive criticism and ideas are constantly flowing into the new editions as they appear.

A necessary requirement for the success of the project is administrative support.

First I wish to thank the Directer of the Gymnasium in Wörth, OStD Rössler for not only allowing us the opportunity of working there, but actively supporting us.

I thank the ministry of education of Rheinland-Pfalz and the regional government of Rheinhessen-Pfalz for approving our school trials.

My gratitude also goes to RSD G. Offermann in Baden-Württemberg and StR M. Strauch in Rheinland-Pfalz. They made possible the large trials taking place at the moment in those two states.

Karlsruhe, August 1989 *F. Herrmann*

Preface to the second Edition

More than 1000 students have participated in the successfully completed trials in Baden-Württemberg and about 500 did so in Rheinland-Pfalz. I wish to express my gratitude to all the colleagues that participated in these trials. In particular, I wish to thank StR N. Krank of the Oberschulamt in Stuttgart and OStD Dr. M. Kobelt of the Oberschulamt in Karlsruhe who both actively supported the school trials in Baden-Württemberg as well as taking part in many of the meetings with teachers involved with the trials.

Many of the suggestions resulting from the school trials have been worked into the second edition. In Baden-Württemberg, a new group is already applying the Karlsruhe Physics Course to their teaching.

In addition to the experiences gained from the previous trial phase, some new chapters have been added to the second edition. They have just been completed within the last year. Among them are Momentum as Vector, Torque and Center of Gravity, Angular Momentum and Angular Momentum Currents, and Compressive and Tensile Stress. In addition, the Teacher’s Manual for both volumes has finally been completed.

Despite all good intentions, the two volumes are too large. We would have liked to make some chapters appreciably shorter. However, standard curricula requirements made this impossible. We would have liked to shorten the chapters on torque and center of gravity, hydrostatics and most of all, optics.

I had the opportunity to teach an abbreviated version of this physics to some classes at the middle school level. It became apparent that the Karlsruhe course is especially suited to this. I taught 8 hours of mechanics and 8 hours of thermodynamics and found that very fundamental and practical teaching goals could be met for both subject areas within this time frame.

A third volume is being worked on at the moment. It will contain chapters about physical chemistry, waves, atomic physics, nuclear and particle physics, solid state physics, electronics and astrophysics. The school trials, which have been running for two years now, are being carried out by my PH.D. student M. Laukenmann and myself at the Europa-Gymnasium in Wörth.

Karlsruhe, April 1993 *F. Herrmann*

Preface to the third Edition

The third part of “modern physics” is finally complete. I wish to thank Dr. Laukenmann and Mrs. Haas for their participation.

Some corrections have been made in Parts 1 and 2.

Karlsruhe, September 1995 *F. Herrmann*

I

Physical Foundations

1. Introduction

This course was developed with the intention of modernizing and streamlining physics education. In order to achieve this, the various areas of physics have been presented from a single consistent viewpoint making learning more economical. The same laws and structures appear repeatedly in mechanics, electricity, and thermodynamics, as well as to a lesser degree in optics, acoustics, and electronics. We need only to learn these general relations once. Understanding that such structures exist is worthwhile because it enhances education in general.

A certain class of physical quantities plays an especially important role in this unification. They are called substance-like quantities.

Streamlining and simplifying instruction is also possible because this method takes modern developments in physics more strongly into consideration than is usually the case. Twentieth century physics has not only brought us new and increasingly difficult theories, but it has shown us that the classical areas of physics (non-relativistic and non-quantum mechanical physics) are simpler than was earlier assumed. Some examples will be given to make this clear.

Mechanics is generally taught today in the same form developed by Newton: A theory of action at a distance. For example, we state that body A exerts a force upon body B without mentioning the medium between them (e.g. a spring or field). In electricity and magnetism, we still speak as if electrical and magnetic interactions are actions at a distance. Since the time of Maxwell, however, we can better describe the effects of force as local effects. This view not only simplifies theory but it is conceptually easier.

Another example that shows how taking modern developments into consideration simplifies physics teaching, is the concept of fields. In the time of Faraday and Maxwell, when physics used the concept of ether, a field was simple. It was a certain state of the ether. When the ether was eliminated from physics, fields became an abstract and difficult concept and remains so today in physics teaching. Modern field theory lends itself well to making fields even more graphic than was done in Maxwell's time. Fields are entities. They are physical systems that are just as real as other material systems. Modern physics suggests making a very concrete view of fields.

Here is a third example of how modern physics leads to a more simplified representation of classical physics. There are many complicated concepts that had a certain validity in earlier times but today are superfluous. Among these is the concept of "form of energy," in particular, "heat" and "work."

Another aspect of the physics presented here is that it establishes connections to other subjects of the curriculum. This will be especially apparent in thermodynamics where the pair of quantities called amount of substance/chemical potential can be introduced right after the pair entropy/temperature. It will be seen that chemical reactions can be dealt with using the same terminology used for mechanical, electrical, and thermal processes.

In recent years, numerous subjects relating to the fast developments in information and communication technology have been added to physics courses. In so doing, it often goes unnoticed that these subjects have more to them than just being a new class of electronic devices. The physics of data transport and data processing deserves a more general treatment than the usual technical one it receives. It fits naturally into the physics course described here because a quantity is used to describe it that does not traditionally appear: Shannon's measure for amount of data.

2. Substance-like quantities

There is a class of physical quantities that easily lend themselves to graphic visualization and understanding. They are called substance-like quantities (Falk 1977, Falk 1979, Schmid 1984). Among them are mass, energy, electric charge, momentum, angular momentum, entropy and others. Each one of these quantities can be imagined as a kind of substance or fluid. The word "imagine" means that when speaking about them, the same vocabulary that is used in every-day life to account for substances can be applied.

One indicator that a quantity is X substance-like**,** is when it appears in a balance equation:

$dX/dt = I_X + \Sigma_X$

This equation makes a statement about a certain region of space, Fig. 1.1. dX/dt represents the time rate of change of the value of X *inside* the region. Σ_X indicates how much of the amount of X is created or destroyed per unit time. It also refers to the interior of this spatial region. The quantity I_X, on the other hand, refers to the *surface* of the region.

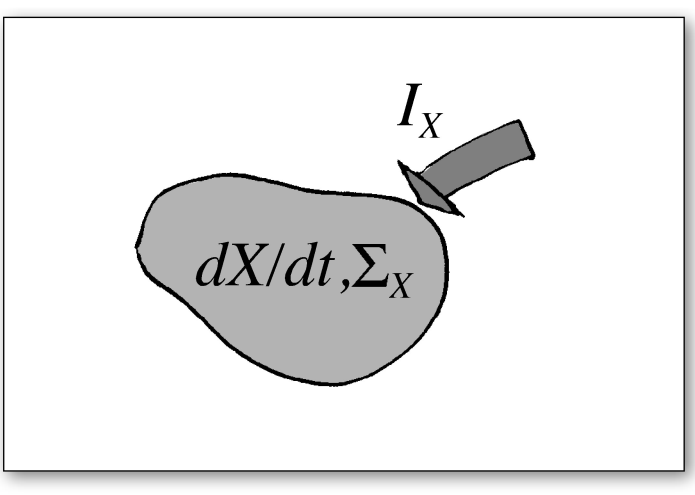

Fig. 1.1
The value of quantity X in the interior of the region shown can change as the result of inflow, outflow, production or destruction.

The balance equation can be made sense of by interpreting I_X as the strength of a current through the surface of the spatial region (Herrmann 1986). So there are two causes for the change in the value of X: The creation or destruction of X inside the region, and a current through the surface of it.

For some substance-like quantities, the term Σ_X is always equal to zero. These quantities can only change their value in a spatial region when a current flows through its surface. Such quantities are called *conserved quantities.* Electric charge and energy are examples of conserved quantities. Therefore, the balance equation for electric charge is

$dQ/dt = I.$

I is the electric current. Correspondingly, the following is valid for energy:

$dE/dt = P,$

where P is the energy current or power.

A substance-like quantity does not have to be conserved. The term substance-like quantity is more encompassing than the concept of conserved quantity. It is important to make clear that the question of conservation or non-conservation only makes sense with substance-like quantities. Only in the context of substance-like quantities does it make sense to ask the question of whether they are conserved or not. The question makes no sense in the case of non-substance-like quantities such as field strength or temperature.

A substance-like quantity does not need to be scalar either. Momentum and angular momentum are examples of vectorial substance-like quantities. A vectorial substance-like quantity can be considered as three scalar quantities where one balance equation is valid for each of the three vector components independently.

The claim that a substance-like quantity satisfies a balance equation implies some simple properties of these quantities:

- The value of a substance-like quantity refers to a spatial region.
- Every substance-like quantity has another quantity belonging to it that can be interpreted as a current.
- Substance-like quantities are additive. If the quantity X has the value X_A in a system A and the value X_B in a system B, it has a value $X_A + X_B$ in the system resulting from putting A and B together, Fig. 1.2.
- Currents are additive as well. If two currents with the values I_{X1} and I_{X2} flow into a region, a total current of $I_{X1} + I_{X2}$ flows into that region.

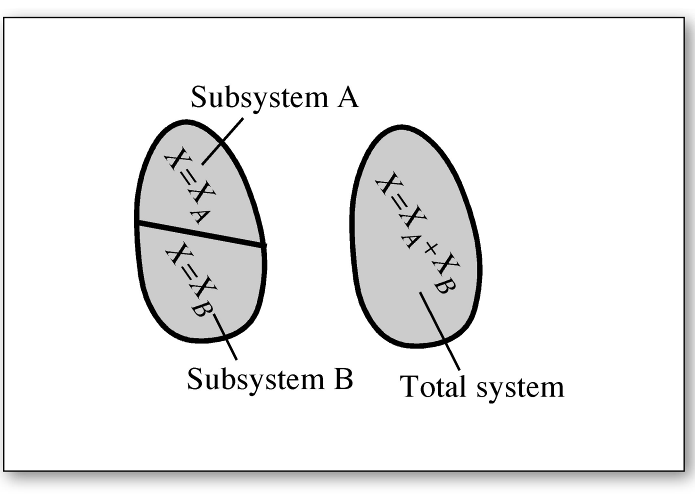

Fig. 1.2
The additivity of substance-like quantities

These are the four properties of substance-like quantities that make them so easy to deal with. They show why we can speak about such a quantity as we speak about a substance.

It is exceedingly valuable for the teaching of physics that certain quantities can be discussed in the same way as substances such as water or air.

When learning a new physical quantity, it is usually necessary to acquire the terminology (verbs, adjectives, and prepositions) that goes with it.

There isn't much leeway in the formulation of sentences where the quantities of force, work or voltage appear. A force is *exerted* upon a body or it *acts* upon a body. Work is *performed*, and a voltage *is present.*

In contrast, all the everyday expressions can be used for substance-like quantities that are used to express balances of substances so that it is possible to say: "A body contains a certain amount of momentum" as well as "There is momentum in the body," "The body has momentum," or "There is a certain amount of momentum in the body". The words *much* and *little* can also be used: A system can have much or little energy in it (but not much or little temperature). It is also possible to say that a system has *no* charge or *no* momentum in order to express that the value of the charge or momentum equals zero. (However, one should not say that a system has no potential or density). The flow of a substance-like quantity can also be described with everyday words. One can say that the electric charge *flows* from A to B. It *goes* from A to B or it *leaves* A and *arrives at* B.

This language is known to every child before he or she has ever had any physics. For this reason, emphasizing the substance-like character of these quantities is very useful for the teaching of physics.

Traditional teaching does not always make use of these advantages. The only quantities that are introduced as substance-like quantities are mass and electric charge. On the other hand, energy and momentum are usually derived from other quantities. This makes it more difficult to comprehend that these are also substance-like quantities.

The fact that one usually does not view energy as a substance-like quantity is expressed in the following sentences which describe the process taking place in Fig. 1.3. "Work is being performed on the capacitor plate on the right, thereby increasing its potential energy in the field of the one on the left." The same state of affairs can be expressed by taking the substance-like character of energy into account: "Energy flows through the rope and the right-hand capacitor plate into the field of the capacitor."

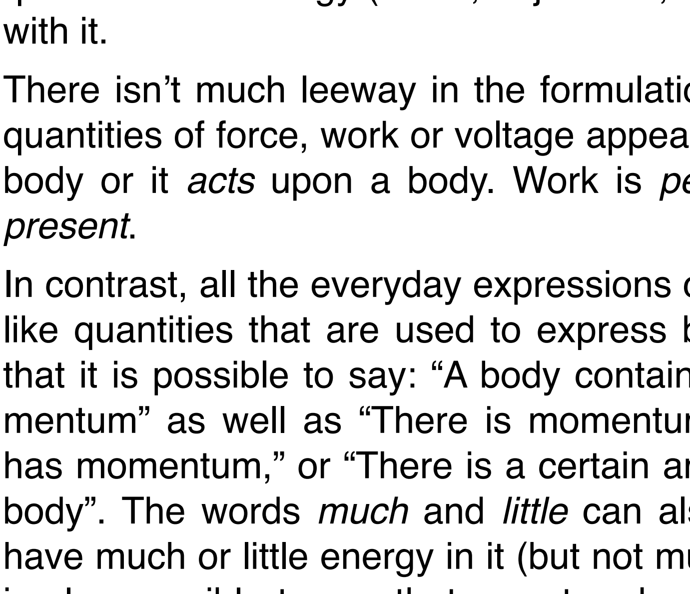

Fig. 1.3
Energy flows into the field of the capacitor through the rope and the plate on the right.

The following sentence demonstrates that no substance-like perception of momentum (the *quantitas motus* or *quantity of motion*) is being conveyed, Fig. 1.4: "Force is exerted upon the car by the rope, changing the car's momentum." By acknowledging the substance-like characteristic of momentum, the same statement can be simplified to: "Momentum flows through the rope into the car".

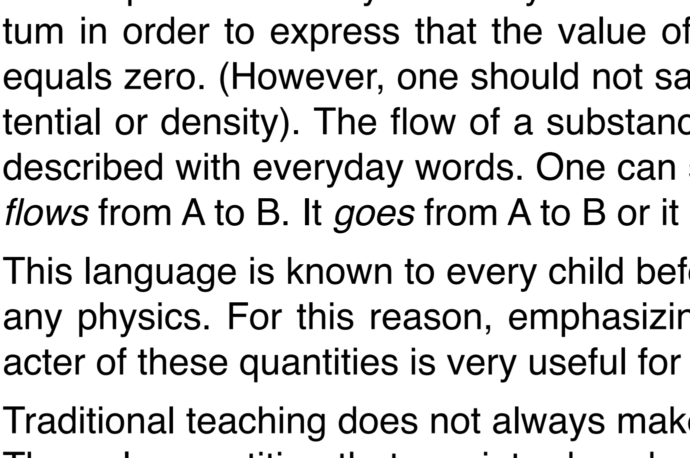

Fig. 1.4
Momentum flows through the rope into the cart.

These two examples show that one does not take advantage of the possibility of creating simple mental representations of certain quantities. Traditional physics teaching has yet another shortcoming. There are areas of physics where no substance-like quantities are used at all. These include optics and acoustics (in modern language: the areas of physics having to do with data technology). The substance-like quantity most appropriate for setting up laws of balance within these sub-areas is Shannon's amount of data. This quantity has not been established in teaching optics and acoustics because it is difficult to bring a fundamental change to fields with a long tradition.

3. Energy forms and energy carriers

The physical quantity "energy" is often given adjectives or determinatives. One speaks of kinetic, potential, electrical, chemical, and free energy, or of atomic, heat, rest, or radiation energy. There is no unified principle for categorizing energy into these different forms. It is done using various criteria. Some of these attributes only indicate a system or an object the energy is in. For instance, the term radiation energy means nothing more than the (total) energy of radiation being considered, exactly as electron charge is the charge of an electron, and solar mass is the mass of the sun. In most cases, though, there are wider implications behind the naming of a form of energy than just its name.

The move to classify energy into different forms arose in the middle of the 19th century when the concept of energy itself was born. The existence of a new physical quantity was inferred even though there were no general characteristics for it or general ways of measuring its values. Energy manifested itself in various ways in the most diverse systems and processes. It was only possible to determine that one was dealing with the same quantity by noting that in different processes, certain combinations of other physical quantities changed at a certain proportion. Obviously, there existed "exchange rates" between these combinations of quantities. These were called equivalents. The best known among them was the *mechanical equivalent of heat.*

Recognizing these combinations of quantities as manifestations of one and the same physical quantity was a great scientific accomplishment. This new quantity was called energy. The energy turned out to be a versatile quantity. Its general nature allowed it to create a connection between the various sub-disciplines of physics. However, it also had a shortcoming. Unlike what would be expected of a respectable physical quantity, energy did not disclose its identity in a uniform manner. For this reason, many physicists considered it nothing more than a mathematical tool. In any case, it appeared reasonable to label the various combinations of quantities representing the different appearances of energy as "forms of energy." Energy did not always reveal itself in the same way, but in some *form* or other. It did not have any invariable property by which its value could always be determined.

This was the view until around the turn of the century and it was reasonable under the circumstances of that time. Later on we will see that in the light of 20th century physics, the concept of form of energy became unnecessary, just as unnecessary as the concept of form of momentum or form of entropy would be. Since the concept of form of energy has remained and has even been upgraded in modern physics teaching, we will explain the foundations of classifying energy into different forms.

When categorizing energy into different forms, one should be aware that there are two different methods of doing so: one allows stored energy (energy contained in the system) to be assigned a form, and the other classifies changes of energy and energy currents. The first method leads to classes such as kinetic energy, potential energy, internal energy, elastic energy etc. The second one leads to categories such as electric energy, chemical energy, heat, work, etc.

In order to differentiate between the categories resulting from these two methods, the first ones are called the existence or storage forms of energy, and the second ones are called exchange forms. We shall start by discussing the storage forms of energy.

The energy E of a system can always be expressed as a function of certain other variables $x_1, x_2, x_3, \ldots$ If these variables are suitably chosen (Falk 1968, p. 54), the system will be completely described by the function

$$E = E(x_1, x_2, \ldots).$$

In mechanical systems, this kind of a function is called the Hamiltonian, and in thermal systems, it is called thermodynamic potential. In a whole range of familiar systems this function decomposes into a sum of terms where each term is dependent upon variables which do not appear in the other terms of the sum (Falk, Ruppel 1976). For example, we could have

$$E(x_1, x_2, x_3) = E'(x_1, x_2) + E''(x_3).$$

In this case, one would say that the system decomposes into non-interacting subsystems.

When such a decomposition is possible, the individual terms can each be given their own name. This is how the existence forms of energy are obtained. A concrete example of this is a moving capacitor whose resulting total energy is:

$$E(Q,\vec{p}) = E_0 + \frac{Q^2}{2C} + \frac{\vec{p}^2}{2m}.$$

Q is the electric charge, C is the capacitance, $\vec{p}$ is the momentum, and m is the mass of the capacitor. The first summand is called the rest energy, the second is called the electric field energy, and the third one is the kinetic energy.

One sees that an existence form simply refers to the energy content of a subsystem. Whenever possible, this fact should be clearly expressed. This is always possible when the subsystem has its own name. In the case of the capacitor, it is more explicit to speak of the *energy of the electric field* or of the *energy within the electric field*, instead of electric field energy.

We will now discuss the definition of the exchange forms of energy. Our experience tells us that in each transition of a system from one state to another, at least two extensive quantities change their values. This fact is expressed by the so-called Gibbs Fundamental Form (Falk, Ruppel 1976):

$$dE = TdS + \phi dQ + \vec{v}d\vec{p} + \mu dn + \ldots \qquad (3.1)$$

Here, T is the absolute temperature, S is the entropy, ϕ is the electric potential, Q is the electric charge, $\vec{v}$ is the velocity, $\vec{p}$ is the momentum, μ is the chemical potential, and n is the amount of substance.

This relation says (among other things) that at each change of energy, at least one more *extensive* quantity (S, Q, $\vec{p}$, n…) changes its value. Most extensive quantities fulfill our criterion for substance-like behavior. The associated *intensive* quantities (T, ϕ, $\vec{v}$, μ…) determine how strongly the energy changes when the extensive quantity changes. The extensive and intensive quantities in a term of the Gibbs fundamental form are said to be *conjugated*, or put more precisely, energy-conjugated. T and S, or μ and n are energy-conjugated quantities.

A Gibbs Fundamental Form can be written for every process. In the simplest case there would be only one summand. What form the change of energy takes depends upon which summands are non-zero upon a change of energy. If TdS is the only non-zero term, then the energy has changed in the form of heat. The term ϕdQ represents electric energy, the term $\vec{v}d\vec{p}$ means mechanical work, and the term $\mu\, dn$, chemical energy.

Now one can imagine any change of energy of the form ydX as the result of a current of quantity X flowing into or out of the system in question. It follows that an energy *current* can be written as a sum:

$$P = TI_S + \phi I + \vec{v}\vec{F} + \mu I_n + \ldots \qquad (3.2)$$

This equation shows that energy currents can be divided into the same forms as changes of energy. Energy can flow in the form of heat or work, in electric or chemical form, etc..

Equation (3.2) expresses a simple and important but unfortunately little known fact: Whenever energy flows, at least one other (substance-like) quantity flows simultaneously. This can be expressed in the simple phrase: "Energy never flows alone."

It is easy to understand that in the view of 19th century thought, the individual terms in Equation (3.1) and Equation (3.2) were considered "forms of energy" and that devices which take up energy in one form and release it in another were called energy converters. This representation appears unfortunate when viewed from a modern perspective, since it suggests that forms of energy are actually different physical quantities having the remarkable property that one can be converted into another.

The special theory of relativity has shown that energy is an independent quantity and not a "derived" one. Seen from a modern perspective, it seems just as unsubstantiated to speak of forms of energy as it is to speak of different forms of electric charge based upon whether it is carried by electrons, protons or muons (Falk, Hermann, Schmid 1984). The theory of relativity tells us what the general characteristics of energy are. The equivalence of mass and energy tells us that energy has the same characteristics as mass: Gravity and inertia. (The general theory of relativity even states that gravity and inertia are one and the same property).

It is unnecessary to speak of various forms of energy in order to distinguish between different terms in Equation (3.2) characterizing transports of energy. It suffices to indicate which substance-like quantity is transferred along with energy. For example, instead of referring to energy in the form of heat, one can simply say that entropy flows along with the energy.

Furthermore, equation (3.2) suggests a simple image for describing a transport of energy. The substance-like quantity accompanying the energy current may be called the *energy carrier.* Metaphorically speaking, energy is carried by entropy, electric charge, momentum, amount of substance, etc. Depending upon the value of the relevant intensive quantity, any given carrier current can be linked to a larger or smaller energy current: We say that the carrier can be charged (or loaded) with a lot of or a little energy.

So the intensive quantity represents a *measure of how much a carrier is charged* with energy. In devices that are usually called energy converters, the energy changes its carrier. It enters the device with one carrier, changes inside the device to another carrier, and leaves it with the new carrier.

Substance-like quantities that characterize various ways of transporting energy are not available for physics beginners. In place of physical quantities, flowing substances will be used as energy carriers. For example, the energy carrier in a central heating pipe will not be called entropy, but simply warm water. Another example would be energy transport through a gas pipe. We will not say that energy is carried by an amount of substance, but by the gas (Falk, Herrmann 1981, Herrmann 1981b).

4. Structures in physics

Equations (3.1) and (3.2) demonstrate a systematic structure of physics. The terms on the right sides of the equations have the same structures ydX and yI_X, respectively, where y is an intensive quantity, X an extensive, substance-like quantity, and I_X represents the current of X. It becomes apparent that each of the terms ydX and yI_X can be attributed to some major classical branch of physics because each term contains only quantities that are characteristic for one such an area. This classification is represented in Table 4.1.

	Extensive quantity	Current	Intensive quantity
Mechanics	Momentum $\vec{p}$	Force $\vec{F}$	Velocity $\vec{v}$
Electricity	Electric charge Q	Electric current I	Electric potential ϕ
Heat	Entropy S	Entropy current I_S	Temperature T
Chemistry	Amount of substance n	Substance current I_n	Chemical potential μ

Table 4.1
Mapping of quantities to branches of physics and to chemistry

If only one of the terms on the right side of Equation (3.2) is not equal to zero, the equation reduces to

$$P = y \cdot I_X \qquad (4.1)$$

This relation describes a transport of energy belonging to a corresponding branch of physics.

The mapping shown in Table 4.1 forms the basis of an analogy between branches of physics which reaches much further than may be expected at first sight. It allows mapping of physical quantities, relations, processes, phenomena and devices from one field onto another. This mapping of mathematical structures suggests to apply the same models and mental representations in the different areas of physics. This textbook will make great use of the possibility to do this. The streamlining of physics teaching presented here rests mostly upon this analogy.

We have seen that in each of the branches of physics listed in Table 4.1, two substance-like quantities play an important role. One of these is the energy and the other is the quantity for the area of physics in question (shown in Column 2). We see that the two substance-like quantities for mechanics are energy and momentum and that energy and charge are the ones for electricity. In thermodynamics, they are energy and entropy, and in chemistry, energy and amount of substance.

Representing such a branch always becomes problematic when one attempts to do it with just one substance-like quantity. It has taken a long time for this view to establish. The famous controversy between Cartesians and Leibnitzians about the „true measure for force“, dealt with the question of whether momentum or kinetic energy was the “correct” quantity. It was assumed that only one of these could exist.

Although both of the substance-like quantities of thermodynamics, energy and entropy, have been known for more than 100 years, teachers today still attempt to teach as much of thermodynamics as possible without a reference to entropy. The daunting traditional set-up of thermodynamics is a result of this. Table 4.1 shows that such a representation of thermodynamics corresponded to a theory of electricity which operates without electric charge and without electric current (Fuchs 1986), or mechanics in which there is no momentum or force.

Our previous observations demonstrate that energy takes a superordinate role in physics. Energy is equally important in mechanics, thermodynamics, and electricity. Interestingly, there is another quantity that fulfills such a function: Amount of data—the quantity with the unit called bit.

Just as energy transports can be classified according to *energy carriers*, data transports can be assigned to corresponding *data carriers*. Moreover, in the same way that every energy carrier characterizes a certain branch of physics, each data carrier belongs to a certain branch of physics or technology. For example, data transport using the data carrier *light*, is characteristic of optics. The data carrier *sound* belongs to acoustics, and in electronics, the data carrier is electricity, Table 4.2. Details about this analogy between energy and amount of data can be found in *Daten und Energie* (Herrmann, Schmälzle, 1987).

	Data carrier
Optics	Light
Acoustics	Sound
Electronics	Electricity

Table 4.2
Data processing technology and associated fields of physic

5. The concepts of current, drive, and resistance

In Section 3 we have seen how it is possible to get a pictorial idea of an intensive quantity. The quantity I_X can be interpreted as the intensity of the energy carrier's current and the intensive quantity y can be viewed as a measure of how much the carrier is charged (or loaded) with energy.

We will now consider a second image that can be made of intensive quantities. The idea itself is well known and widespread but usually it is only applied to electricity. Its strength lies in the fact that it can be just as useful when applied to mechanics, thermodynamics and chemistry. As an example, we will illustrate it in the familiar context of electricity.

An electric current flows through a resistor which does not need to be an ohmic resistor, Fig. 5.1. The words we use to describe this situation already touch on the image we are dealing with. We speak of "current" if the quantity I has a value different from zero and we call the device in which entropy is created, a "resistor". It is this image that every physicist unconsciously uses and which we wish to expand and use extensively in physics teaching.

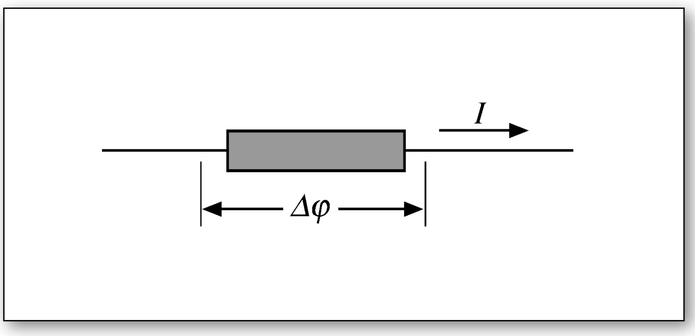

Fig. 5.1
We interpret the potential difference across the resistor as the driving force of the electric current.

We call the quantity I the intensity of the current of the quantity Q. The fact that the current flowing through the device in Fig. 5.1 is greater the higher the potential difference, can be interpreted as follows: The potential difference or voltage is what "drives" the current. In this image, the current does not flow on its own because the resistance of the object through which it flows, hinders it.

That this interpretation is rather arbitrary can be seen in the case of ohmic resistance. We have

$$U = R \cdot I .$$

The equation states that U is proportional to I : The greater U is, the greater I is and vice-versa. However, it says nothing at all about which of the two is the cause of the other. It does not state that the voltage is the cause of the current nor does it say the reverse. It is arbitrary to assert that a voltage is the cause of a current. We generally find it more natural to consider the voltage as the cause. This is because voltage is usually easier to select than current. When the current is actually given, for instance with the help of a current stabilized power supply, one actually speaks of a potential "drop" which is "caused" by a current.

Despite its arbitrariness, this image is very useful to the student studying electricity or trying to solve problems of electronics because one can orientate oneself by means of the phenomena this image originates from: currents of liquids and gases, or more concretely, of water and air.

But above all, we make use of this image because it is not only useful in electricity but in mechanics, thermodynamics, and chemistry as well.

The image of driving force and resistance can be just as useful for gaining an understanding of intensive as for extensive quantities. It is helpful in electricity for forming a view of the intensive quantity called electric potential. In chemistry, we use it to introduce the intensive quantity called chemical potential. However, when dealing with temperature which is the intensive quantity of thermodynamics, pupils and students already have a pretty good idea of what that is. Here, the image of drive (driving force) and resistance helps in introducing the extensive quantity entropy.

We have put a teaching unit about currents of fluids and gases at the beginning of the course so that the students can become familiar with this model. Many of the course's most important concepts are developed in this chapter.

One sees that the idea of driving force and resistance fits well to the unified structure of physics discussed in the previous section and contributes to a simplification of the teaching of physics.

6. The most important quantities and relations

Here is an overview of the most important quantities which will be dealt with in this course.

Extensive (substance-like) quantities

Energy E
Momentum $\vec{p}$
Angular momentum $\vec{L}$
Electric charge Q
Entropy S
Amount of substance n
Amount of data H

Intensive quantities

Velocity $\vec{v}$
Electric potential ϕ
Temperature T
Pressure p
Chemical potential μ

Currents

Energy current (= power) P
Momentum current (= force) $\vec{F}$
Electric current I
Entropy current I_S
Current of amount of substance I_n
Data current I_H

In addition, some quantities that do not belong to any of these three categories will be introduced. Among them: Position, time, some material constants and some quantities that characterize technical devices such as spring constant D, electric resistance R, and capacitance C.

The mathematical relations in which these quantities appear can be classified according to the structure discussed in the previous sections. A relation in one class can be obtained by formal translation of the corresponding relation of any other class. Translation means taking a quantity of one line of Table 4.1 and replacing it with the quantity from another line from this table. Only energy and energy currents must not be replaced.

The most important relations dealt with are compiled in Table 6.1. Each column contains the relations belonging to a class. Each line corresponds to one of four disciplines: Mechanics, electricity, thermodynamics, or chemistry. The quantities in Table 4.1 are arranged this way as well.

Relation between amount and current	Relation between current and carrier current	Capacities	Resistances
$F = p/t$	$P = v \cdot F$	$m = p/v$	only qualitatively
$I = Q/t$	$P = U \cdot I$	$C = Q/U$	$R = U/I$
$I_S = S/t$	$P = T \cdot I_S$	$\Delta S/\Delta T$ (no symbol)	only qualitatively
$I_n = n/t$	$P = (\mu_2 - \mu_1) \cdot I_n$	not treated	only qualitatively

Table 6.1
The most important relations

The equations in column 1 of table 6.1 describe the relation between the time rate of change of a substance-like quantity and its current. Actually, the differential quotient should stand in the place of the quotients of substance-like quantity and time. For this reason, these equations are only valid if the corresponding current is constant in time. The following equations also belong to these relations:

$P = E/t$

and

$I_H = H/t.$

However, they do not belong to any line in Table 6.1.

The relations in column 2 describe the connection between the energy current and the current of the substance-like quantity accompanying the energy current. The forms of these equations are like those in Equation (4.1). They define the scales of the intensive quantities (they explain how the multiples of these quantities are formed).

The quotients in column 3 could be called generalized capacitances because they have all the same structure as the electric capacitance. For instance, the mass of a body could be understood as its momentum capacitance. At a given velocity, the body will contain more momentum the greater its mass is. There is no usual sign for the entropy capacitance $\Delta S/\Delta T$ even though it is a technically important quantity. It is the measure of the heat storage capacity of a body.

With the exception of Ohm's law, the relationship between current and driving force in dissipative processes (column 4) will be dealt with only qualitatively: The greater the current's driving force, the greater the current.

7. The scales of the most important quantities

When a new physical quantity is introduced, it must be explained how the multiples of its unit are defined. The method for determining a scale (meaning the multiples) is basically the same for quite a number of quantities. In particular, each of the three classes discussed in the last section has its own method for determining a scale. We will limit ourselves to a discussion of these three classes.

Defining the multiples of a substance-like quantity is conceptually trivial. In order to produce double (or triple, etc.) the value of a substance-like quantity, one only needs to double (or triple, etc.) the entire system. If one wishes to increase the value of a substance-like quantity of a single system by 1, 2, ... *n* units, one must transfer 1, 2, ... *n* units of the quantity to the system. Sometimes, this transfer is very easy, for instance in the case of electric charge by use of a Faraday beaker, Fig. 7.1. In other cases, such as energy, this procedure can be complicated.

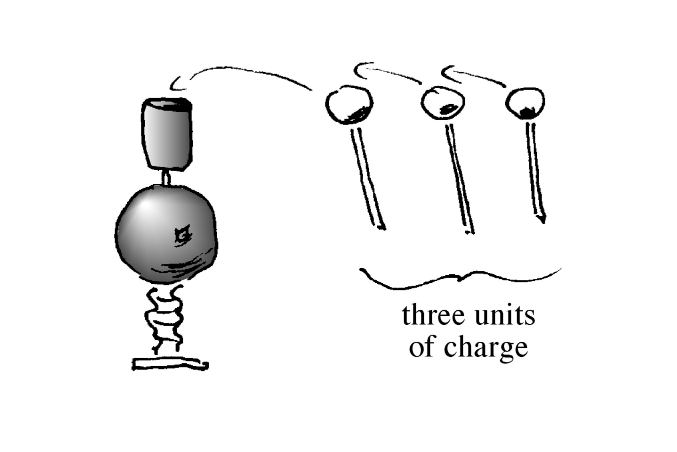

Fig. 7.1
The electric charge of the large sphere is increased by three units.

In order to define multiples of currents, we consider a current flowing through a conductor with a well-defined cross-sectional area. The current should not have any source or sink in the conductor. In order to realize multiples of the current, we apply the junction-rule. We allow 1, 2, ... *n* unit currents to flow from a node into the conductor. Fig. 7.2 shows the realization for an electric current, Fig. 7.3 shows it for a force, i.e., a momentum current.

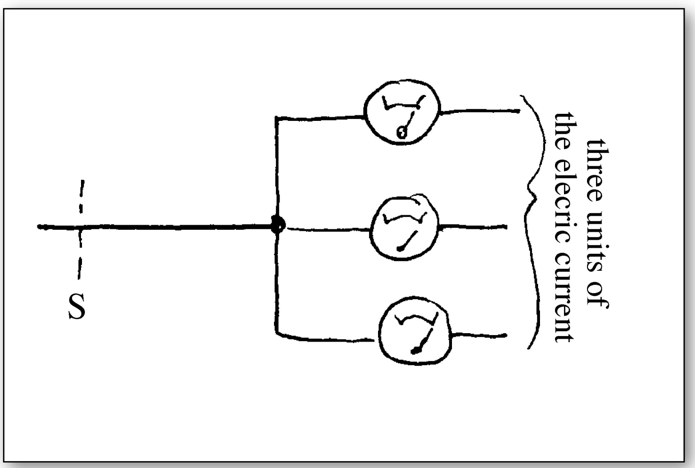

Fig. 7.2
Three units of an electric current flow through cross section S.

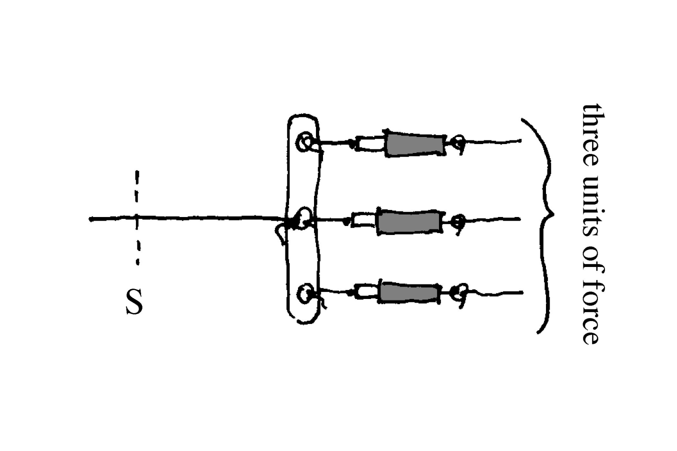

Fig. 7.3
Three units of a momentum current flow through cross section S.

Defining scales for intensive quantities is more complicated. As already stated, it is done by use of the equations in the second column of Table 6.1. We will illustrate this using the example of electricity. We compare two electric circuits A and B, Fig. 7.4. Both should have the same electric current. Now if the energy current in circuit A is twice that of circuit B, then the voltage in A is also twice that of B.

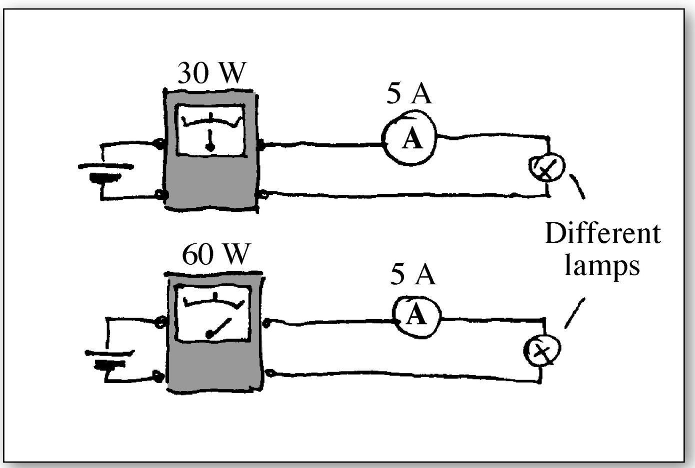

Fig. 7.4
In the lower picture, the energy current *P* is double that in the upper picture. The electric currents *I* are equal. The voltage scale is defined so that *P* = *UI* holds in both cases.

Although determining the scale of a quantity is an important step in defining the quantity, we suggest not spending too much time on this question in middle school because the problem of forming multiples is almost always trivial, or else it is difficult.

8. Literature

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II

Remarks

1. Energy and energy carriers

1. Energy as a substance-like quantity

Energy is introduced as a quantity with a substance-like character. We refer to energy just as we would refer to a substance. This makes dealing with energy easier than it would be if it were introduced in the traditional manner, i.e. via the concept of work.

2. Physical quantities or substances as energy carriers?

The introduction of energy carriers is based on a law which states that each time energy is transported, at least one other substance-like quantity is also transported. In mechanical energy transport, this quantity is momentum and in an electric transport, it is electric charge. In thermal transport, it is entropy and in chemical transport, it is amount of substance. We suggest calling these quantities which accompany the energy current, energy carriers.

In order not to burden beginning instruction with a great number of new physical quantities, we will not call these quantities energy carriers, but replace them with names of substances which themselves “contain” these substance-like quantities. At the beginning, it is then possible to speak of the energy carrier “warm water” or “hot air” instead of entropy, and instead of amount of substance, we can say that “gasoline” or “heating oil” is the energy carrier.

3. Angular momentum as energy carrier

In the same way force is interpreted as a momentum current, torque can be seen as a current of angular momentum. The equation

$$\vec{M} = \frac{d\vec{L}}{dt}$$

(where $\vec{M}$ = torque, $\vec{L}$ = angular momentum) means that the time rate of change of the angular momentum of a body equals the angular momentum current flowing into the body.

4. “Deposit-bottle” energy carriers and “one-way-bottle” energy carriers

There is no deeper physical meaning behind deposit-bottle energy carriers and one-way-bottle energy carriers. We only introduce these concepts because it is a good way to learn to distinguish between the path of the energy and the path of the energy carrier. It is easy to see that a deposit-bottle transport can be transformed into a one-way-bottle transport, and vice-versa. For instance, the air streaming out of a jackhammer can be conducted back to the compressor so that it becomes a deposit-bottle energy carrier.

We have introduced angular momentum as a deposit-bottle energy carrier. This is justified in most cases—for instance when an electric motor and the pump which drives it are mounted to the same foundation or are in the same casing. The angular momentum flows through the motor’s drive shaft from the motor to the pump and through the foundation or casing from the pump back to the motor.

It is different if the motor drives a fan wheel, for instance. In this case, the angular momentum goes from the motor through the drive shaft to the fan wheel where it is distributed into the air. It then returns to the earth in a way which is difficult to control, and finally back to the motor. It might be tempting here to refer to the angular momentum as a one-way-bottle energy carrier, but we have abstained from this fine distinction.

2. Flows of liquids and gases

1. Air and water flows as models for flows of physical quantities

In this chapter, concepts and structures are introduced which later will be used over and over again.

The objects of consideration—air and water flows—are well known to the student. Not only can water be seen, it is usually clearly apparent whether or not it is flowing. Students also have a clear idea about air currents.

The currents being considered here are currents of substances, but later on, currents appear which are more abstract. These are the currents of physical quantities. The concepts and relations which are introduced in this chapter can easily be carried over to the currents of physical quantities. In particular, we want the mental models formed by the students about these processes to be transferred to currents of physical quantities.

2. Some basic concepts

The following concepts and relations will appear again numerous times in the course:

– *Current*. The amount of a substance or an extensive physical quantity which flows through a certain surface area in a specified amount of time, divided by this time span.

– *Driving force or drive.* The difference between the values of an intensive quantity. The greater the drive, the greater the current.

– *Resistance.* A characteristic of a conductor which depends upon length and cross-section.

– *Equilibrium.* The state in which no current flows, although a conductive connection exists; there is no driving force.

– *Junction rule*. Consequence of the balance equation when no source or sink exists.

– *Loop rule.* Any point on a conductor can be assigned a value of the intensive quantity.

– *Energy carrier.* The current of a substance or an extensive quantity is related to an energy current.

3. A measure of air and water currents

We use the volume as a measure of the quantities of fluids and gasses. Despite this, we speak of water and air currents, and not of volume currents because there is no physical quantity called volume current.

4. Currents of substances have more than just one driving force

A number of physical quantities flow along with every current of a substance. This means that there are also a number of different drives for the flow of the substance. For every extensive quantity that flows with the substance, there is an intensive one as well. The gradient of this intensive quantity can result in a current of the substance in question. For instance, a fluid flow is not only driven by a pressure difference, but also by a difference in gravitational potential. In other words, it flows downward by itself. For the sake of clarity, in this chapter we will just consider configurations where only pressure differences play a role.

5. Pressure as an independent quantity

Pressure will not be defined by means of the force, as is usually the case (“Pressure equals force per surface area”), because force is certainly the more difficult of these two quantities. Arithmetic signs, the problem of the direction and the concepts of reaction force and equilibrium are what makes dealing with forces so difficult. In this regard, pressure is simpler. It is—at least in our examples—a scalar, whose value refers to a point in space. It is not necessary to indicate what is being pressed by what (as is necessary in the case of force). Moreover, in our examples of gas and fluid currents, the pressure values will always be positive.

3. Momentum and momentum currents

1. Momentum right from the beginning

In this physics course, mechanics is characterized as that area of physics which deals with the substance-like quantity momentum and its currents. This being the case, it is logical to begin teaching with the quantities $\vec{p}$ and $\vec{F}$.

This approach differs from traditional school physics in which force is introduced early on, but momentum only much later, if at all. This appears to us to be unnatural because one deals with the current of something without saying anything at all about what is actually flowing.

A result of our approach is that certain mechanical phenomena will be interpreted differently and that other images are drawn upon to explain them. Moreover, other phenomena are made the objects of discussion. The phenomena usually attributed to dynamics play a greater role in this course than in the traditional teaching at middle school.

2. Force as momentum current

Historically, interpreting the quantity $\vec{F}$ as the intensity of a momentum current established itself at the same time that momentum was beginning to be accepted as an independent quantity (at the turn of the 19th to 20th centuries). As far as we know, the idea came from Max Planck (1908). It can then be found in numerous publications at the beginning of the 20th century (for example, Weyl 1924). The general theory of relativity definitely established momentum as an independent quantity. In the energy-momentum tensor, momentum appears along with energy, energy current density and momentum current density as a source of the gravitational field.

Momentum is more than an abbreviation for the product $m \cdot \vec{v}$, since there are systems whose momentum cannot be calculated according to $\vec{p} = m \cdot \vec{v}$. An example is the electromagnetic field. The momentum density of the electromagnetic field is calculated as

$$\rho_p = \frac{\vec{E} \times \vec{H}}{c^2}$$

where $\vec{E}$ is the strength of the electric field and $\vec{H}$ is the strength of the magnetic field.

Although $\vec{F}$ was acknowledged as momentum current almost a hundred years ago, the idea has still not become established. It can be found in many modern physics textbooks (Landau and Lifshitz 1959; Gerthsen, Kneser, Vogel 1977) but always appears as an approach only for the advanced student. It seems never to have been considered that this concept could be understood by beginners and physics made easier to understand because of it.

Of course, such an approach to mechanics stands in opposition to the tradition of the teaching of physics.

3. Conductive and convective momentum currents

The law of balance for momentum

$$\frac{d\vec{p}}{dt} = \vec{I}_p$$

states that the rate of change of momentum, $d\vec{p}/dt$, inside a region of space is equal to the intensity $\vec{I}_p$ of the momentum current through the surface of the region.

The momentum current $\vec{I}_p$ can be divided into two parts: the part $\vec{F}$ which is traditionally called force and the part $\vec{v} \cdot I_m$ which appears when a mass flow enters the considered region of space. I_m is the mass flow. This last part is what is responsible for the acceleration of a rocket. It is coupled with a mass flow, so it can be called a "convective" momentum current, and the part $\vec{F}$ is, correspondingly, a "conductive" one.

These two parts differ from each other in their behavior when changing the reference system. The convective part changes its value whereas the conductive part does not. In the reference system where the velocity $\vec{v}$ of the term $\vec{v} \cdot I_m$ equals zero, the convective momentum current disappears. For an observer who is moving at the same speed as the water in a water jet, the jet is not transporting any momentum and of course, the mass flow also disappears.

4. Newton's laws in the momentum current model

Table 3.1 contains a translation of Newton's laws into the language of momentum flow. The formulations on the right side of the table shows that all three laws are different formulations of the conservation of momentum.

	Traditional formulation	*Formulation using the momentum current image*
1 st law	If there are no forces acting on a body, the body will stay at rest or move uniformly in a straight line.	If no momentum currents are flowing into or out of a body, the momentum of the body will not change.
2 nd law	The time rate of change of the momentum of a body $d\vec{p}/dt$ equals the force $\vec{F}$ acting upon the body: $\vec{F} = d\vec{p}/dt$	The time rate of change of the momentum of a body $d\vec{p}/dt$ equals the momentum current $\vec{F}$ flowing into the body: $\vec{F} = d\vec{p}/dt$
3 rd law	If body A exerts a force $\vec{F}$ upon body B, then body B exerts an equal but opposite force $-\vec{F}$ upon A.	If a momentum current flows out of a body A and into a body B, the intensity of the current leaving A is the same as that entering B.

Table 3.1
Translation of Newton's Laws to the momentum current language

Since in our course we assume right from the beginning that momentum is conserved, Newton's laws never need to be dealt with.

Thus, we proceed in the same manner as one proceeds traditionally in electricity: Usually, the conservation of electric charge is taken for granted.

5. The relation $\vec{p} = m \cdot \vec{v}$

The relation $\vec{p} = m \cdot \vec{v}$ is dealt with rather late. Before, the students should acquire a well-founded idea of momentum as an independent quantity. In so doing, we avoid the idea that $\vec{p}$ is only an abbreviation for the product $m \cdot \vec{v}$ or that the values of $\vec{p}$ can only be determined through those of m and $\vec{v}$.

The relation in electricity which is analogous to $\vec{p} = m \cdot \vec{v}$ is $Q = CU$. Naturally, this equation is not used to define electric charge. It simply states that that the voltage between the plates of a capacitor is proportional to the charge on them. It also defines the capacitance as a factor of proportionality relating Q and U. In just the same manner, the equation $\vec{p} = m \cdot \vec{v}$ tells us that the velocity of a body is proportional to the momentum of said body, and it defines the mass as a factor of proportionality relating $\vec{p}$ and $\vec{v}$.

6. The names of the quantities $\vec{p}$ and $\vec{F}$

There are two common names for the quantity $\vec{p}$, "momentum" and "quantity of motion."

The name "momentum" has the advantage of being short. Moreover, it gives a fairly useful intuitive feeling for what is meant. The expression "quantity of motion" is a translation of Descartes' name for the quantity $\vec{p}$, "quantitas motus." Unfortunately, the translation does not exactly say what Descartes meant. Descartes considered the quantity which he introduced to be a measure of *amount* of motion. This was a very far-sighted perception. The expression "amount of motion" describes what Descartes meant, and the modern idea of what $\vec{p}$ is, much better.

Because the second word is not well chosen, we have decided for the shorter word "momentum."

We do not continue to use the word "force." It contradicts our intention of describing $\vec{F}$ as current strength of the quantity $\vec{p}$.

If we had complete freedom in choosing the names for the quantities $\vec{p}$ and $\vec{F}$, we would call $\vec{p}$ the "amount of motion" and $\vec{F}$ the "mechanical current" (analogous to the electric current I).

7. The unit of momentum

Students should conceive a substance-like quantity as an independent quantity. They should not consider them as derived from other quantities. One would not do these concerns justice if a derived unit, meaning a unit which is a product or quotient of other units, were used for a substance-like quantity. There are no units for momentum or entropy in the Système International, so we will introduce SI compatible units. For momentum we will use the Huygens (Hy) where

1 Huygens = 1 Newton · second

and for entropy, the Carnot (Ct), where

1 Carnot = 1 Joule/Kelvin.

We will, on the other hand, emphasize that the currents of substance-like quantities are derived quantities: The amount which flows by a certain surface area per time span. In the cases where a current has its own unit, namely J/s = W, C/s = A, and Hy/s = N, we will intentionally use the compiled unit. We will say, for example: "A momentum current of 15 Huygens per second flows through a rope, this is 15 Newtons," or "2 Coulombs per second flows through a wire, meaning that the current is 2 Coulombs per second or 2 Amperes."

8. The substance-like character of momentum

One important educational objective in Section 3.2 is the insight that momentum has substance-like character and that bodies in motion contain an "amount of motion". Almost all the ideas and experiments in 3.2 serve this objective. All of the experiments ask for the balance of momentum.

Of course, the question of "Where has the momentum gone?" already presupposes that momentum is substance-like in nature. The teacher might also ask the question: "Wouldn't it be better if the students could discover the substance-like character of the new quantity for themselves?" However, this is a much more difficult goal to achieve. Historically, it took a couple of hundred years for this insight to form. Moreover, we do not deal with other substance-like quantities such as mass or electrical charge, in this way. Right from the start, teachers speak about both of these quantities as one speaks about substance-like quantities. It is highly improbable that students would discover the substance-like character of electric charge for themselves.

9. Regarding the method of teaching

One comment about teaching methods. We make the following suggestion for some of the experiments: The experiment should be demonstrated first. The students should then be asked to describe what they have *observed*. They should do so by speaking about the velocities of the two bodies, for example: "One body moves to the right, the other remains still; then they collide; then both are in motion; etc." Next, the students can be asked to *explain* the experiment. This means that they should explain what has happened to the momentum. Movement is observed, and momentum is used to explain it.

Later, in thermodynamics, we will proceed analogously. The description of what is observed will be done through comments about temperature and the explanation will be accomplished by setting up the balance of entropy.

10. Everyday language for describing momentum

When introducing the subject of momentum, the teacher might first ask the students to give words or expressions which describe what a heavy, fast moving body (for example, a heavy truck driving down the highway at 100 km/h) contains. The teacher then tells the students that it is exactly this which physicists call momentum. We have found that students use not only the words "momentum," "impetus" and "power" but also the word "force."

This answer should not, by any means, be rejected as wrong or inapt. Instead, it should be made clear that the word "force" has no uniform usage in everyday language. Indeed, its meaning in everyday language only occasionally matches the quantity F of physics. Sometimes it describes kinetic energy, sometimes mechanical energy currents, and often it actually fits momentum.

This can also be seen when investigating the historical usage of this word in physics. There was a famous discussion between Cartesians and Leibnitzians about whether mv or mv^2 was the "correct" quantity for finding the true "measure of a force," as it was expressed at that time.

11. Measuring momentum

Fig. 3.1 shows an experimental arrangement for measuring momentum. The body K, whose momentum is to be measured, moves to the right. The bodies E_1, E_2, . . . coming from the right each carry one unit of negative momentum. The bodies E_i collide with K inelastically, meaning that each body E_i which collides with K remains attached to it. The measuring process goes like this: Unit bodies are allowed to collide with K until it comes to a standstill. The number of unit bodies which are attached to K at this point equals the number of momentum units that K had before the first collision.

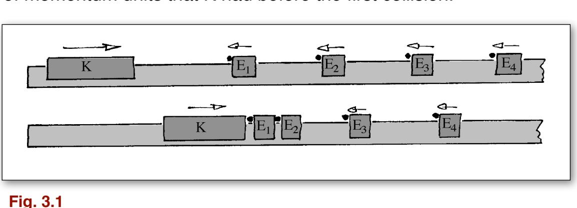

Fig. 3.1
Experiment for measuring momentum

This experiment can be implemented in the following way (Herrmann, Schubart 1989): Body K is a glider on an air track. The unit bodies are air-gun pellets which are pneumatically shot towards K. Body K has a pellet catcher on it. However, this experiment is not appropriate for schools because of the dangers involved. This method of measurement can simply be discussed.

We believe, though, that such a method is unnecessary because the collision experiments discussed in section 3.2 implicitly contain a method for measuring momentum. In particular, equality of momenta and multiples of momentum values are already determined by them.

12. The role of friction

In classical mechanics, friction is an undesirable phenomenon. It has no place in classical mechanics because it is connected with the production of entropy, and therefore leads to non-conservative forces.

Without friction, force is proportional to acceleration. Physicists have gotten so used to frictionless mechanics that some of them tend to believe that the expression "Force is proportional to speed" is incorrect and only the expression "Force is proportional to acceleration" is correct.

Of course, one or the other of these can be correct. The disparagement of the relationship $\vec{F} \propto \vec{v}$ in the mechanics of the 19th century (which could not deal with entropy) is regrettable because it still influences how physics is taught today. The relationship $\vec{F} \propto \vec{v}$ is at most, less fundamental than $\vec{F} \propto \vec{a}$ in that it depends upon material characteristics. By the way, the electric relation $I \propto U$ which is analogous to $\vec{F} \propto \vec{v}$, is not represented as secondary to $I = dQ/dt = CdU/dt$ (the relation between I and U in a capacitor).

In this course, we deal with friction as a normal (and not always unwelcome) mechanical phenomenon. However, it may happen that we wish to exclude it. When this is the case, we use the air-track or a vehicle with good bearings, exactly as we use copper wire in order to eliminate "electric friction."

13. The concept of static friction

In mechanics, we use the word friction to describe a dissipative process, a process in which a momentum current leads to the production of entropy. We consider the entropy production to be characteristic of the process of friction. The word "friction" is also used figuratively, for example when an electric current flows through an electrical resistor.

This concept is, not compatible with the idea of static friction. In contrast to usual friction, static friction is not a process, much less an entropy producing one.

When two bodies adhere to each other, it is physically the same as when they are glued to each other or are welded to each other. The location on the bodies where they touch each other is, physically seen, the same as a predetermined breaking point. This is the location where the momentum conductor's connection breaks down when the momentum current becomes too strong.

14. Momentum currents without resistance

We compare solid objects which are resistance-free momentum conductors with electric superconductors, but we do not actually say that they *are* momentum superconductors. In electrodynamics, the word superconductor represents more than a conductor whose resistance is zero (The 1st London equation). The magnetic field must also disappear in a superconductor (Meissner-Ochsenfeld effect, 2nd London equation).

15. Introducing velocity

Velocity is not introduced by a definition that derives it from distance and time. There are two reasons for this. First, it would appear unnatural to introduce a complicated definition for a quantity that everyone already has a very good idea of. Second, since the derivative is not yet known, velocity can be defined only for the special case where it is constant. Thus, our approach can be summed up as follows: Velocity is the quantity which tells us how fast a body moves. It is the quantity which is measured by a speedometer. In the special case of v = const, there is a simple relation between the velocity v, the distance covered s, and the time t which was necessary for covering the distance, namely $v = s/t$.

16. Average velocity

The term average velocity will not be given more importance than other time averages such as average position, average electric current, average energy...

17. The analogy between momentum and water currents

To demonstrate the balance of momentum, we sometimes compare the momentum in a body to water in a container. The velocity of the body corresponds to the water level. This analogy is just as sustainable as the other analogies that we are using.

The analogy is defined by Table 3.2. Actually, behind the height of the water level the intensive quantity "gravitational potential", gh, is hidden.

Body	Water container with vertical walls
Mass m	Horizontal cross section A of container
Momentum p	Amount V of water (measured in liters)
Velocity v	Level h of the water surface

Table 3.2
Analogy between momentum and water flows

From the relation $p = m \cdot v$ which is valid for the left column, one obtains (through purely formal translation) the equation $V = A \cdot h$ which is correct for the right side.

This "water container model" is probably the simplest realization of the structure which appears again and again in other areas of physics. It is so perfect and obvious that one is tempted to use it whenever possible.

Here is an example: A glider colliding inelastically with two other gliders corresponds to a full container of water connected to two empty ones so that the water levels eventually equalize.

However, such analogies should not be over-used. Although learning the structures of physics is an important goal, real phenomena are just as important and their investigation should not be shortchanged by overemphasizing the amount of time spent on these structures.

The following comparisons are not intended to be used in class. They are meant to make the teacher trust the image of momentum as a substance-like quantity.

A constant momentum current flows into a free-falling body. Its momentum increases in proportion to time. This corresponds to water flowing into a container at a constant rate. As a result, the water level rises in proportion to time. On the moon, the momentum current would be weaker and the model would correspond to a weaker water current.

We consider two falling bodies A and B where A has twice the mass of B. They correspond to two containers where A has twice the base area of B. When the bodies A and B fall freely, twice the momentum current flows into A (as a consequence of $F = m \cdot g$) as flows into B. Therefore, we must allow a current to flow into container A which is twice as strong as the one flowing into container B. The water levels (which correspond to the velocities) rise equally fast, Fig. 3.2.

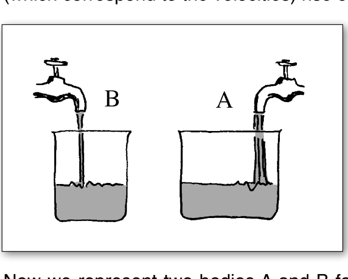

Fig. 3.2
The cross section of the container on the right is twice that of the container on the left. Moreover, the water current flowing into the container on the right is twice that flowing into the container on the left. Therefore, the water levels rise at the same rate.

Now we represent two bodies A and B falling in a resistive medium as water containers, Fig. 3.3. Again, body A should be twice as heavy as body B. Both bodies should have the same form so that, at equal speeds, loss of momentum through friction is the same for each. The velocity-dependent friction corresponds to a hole in the bottom of the container in the water model. The water loss depends upon the level h of the water. The containers have identical openings for the water loss so that if the water levels are the same, the water currents flowing out (loss) are the same. Letting go of the bodies corresponds to opening the water faucets. Exactly in the way that each falling body asymptotically approaches a different terminal velocity, the water levels adjust to two different terminal values. The terminal level for the container with the smaller base area is lower.

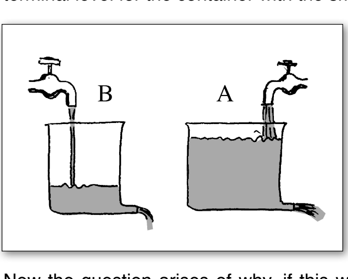

Fig. 3.3
The containers in Fig. 3.2 each have an identical hole. The water levels asymptotically approach a different level.

Now the question arises of why, if this water container model is so simple, is it not used in Chapter 2 where basic concepts such as voltage, drive, resistance, etc. were introduced, but rather a structure where pressure is the intensive quantity? This is because the water container model is rather clumsy for dealing with flow resistance. It is rather difficult to realize an arrangement analogous to ohmic resistance here.

18. Collisions

When two bodies collide, one loses momentum and the other receives it. However, in order to call a momentum transfer process a collision, more is needed. The participating bodies must first be moving without momentum being transferred, then there should be a very short time span of transferal and then another phase of no momentum transfer. The period of time needed for the momentum transfer should be so short that the process itself goes unnoticed by the observer.

In fact, most collision processes are dealt with by setting up balances only. One asks for the bodies' momentum and kinetic energy before and after the collision and not for how the transfer proceeds in time.

There are several reasons for the popularity of collision processes in physics.

Historically, collision processes have played a major role. At a time when technology was much less developed than today, there were only a few processes which were accessible to a rigorous scientific treatment. Besides the free fall and the motion of celestial bodies, there were collision processes. These also had the pleasant characteristic of allowing statements to be made about the results of an experiment without exactly knowing the exact process and without knowing the force law. In fact, the Newtonian concept of force did not even exist when collision laws were formulated.

Just how important collisions were to 17th century mechanics, can be seen in the number of works dealing with this subject by Descartes, Marci, Galileo, Roberval, and others. In the year 1668, the Royal Society of London initiated a work about collision processes resulting in essays submitted by Huygens, Wren and Wallis. Since then, the subject has been handed down from generation to generation.

There are further reasons why collision processes are so popular even today. Collisions are among the topics it is easy to find quantitative problems for. They are also easy to demonstrate on tracks.

The reasons given above explain why collisions play such an important role in teaching, but they do not justify it.

The role these processes play in teaching should depend upon how important collision processes are in everyday life or in physics research. Automobile collisions and billiard ball collisions alone do not justify dealing with this subject and although collisions in particle physics have again gained in importance, this is not a subject for middle school physics.

For this reason, we suggest emphasizing the more common processes of momentum transfer. Among these are:

– A car accelerating or braking;
– A car driving around a curve;
– Falling and throwing processes;
– The motion of the moon, planets and satellites.

All of these processes are so constituted that the time in which momentum flows from one body to the next no longer appears negligibly small. The transfer process itself comes to the fore and itself becomes an object for consideration.

19. Mechanics with momentum of a single direction

In one way, mechanics is the easiest field of physics. Our senses are such that we most easily perceive mechanical processes and our brains simulate mechanical processes with incredible precision. On the other hand, there is a reason why learning mechanics is especially difficult. Mathematical descriptions are more complicated than in other areas of physics because some of the most important quantities of mechanics, namely momentum, force and velocity, are vectors. Mechanical stress, something we have a very good feeling for, is described by a second order tensor, and the elasticity of a material—again easy to visualize—even needs a fourth order tensor.

In order to sidestep these mathematical difficulties, we will at first consider a consistently one-dimensional form of mechanics. We limit ourselves to processes where only one component of momentum, force and velocity plays a role. Mathematically, we can deal with this one component as we would deal with a scalar. It is remarkable that the most important facts of mechanics can actually be described with a minimum of effort.

20. Literature

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4. The gravitational field

1. Introducing mass

We will make a few remarks about how we introduce mass. In section 3.15 of this course, students encounter mass for the first time in an equation, namely the relation $p = m \cdot v$.

On could introduce gravitational mass m_{gr} and inertial mass m_{in} by the following method:

The gravitational mass's scale would be defined through

$F = m_{gr} \cdot g$,

this means that the gravitational mass is defined to be proportional to the force of gravity (for different bodies at a fixed location).

The scale of the inertial mass is defined by the relation

$p = m_{in} \cdot v$,

meaning that the inertial mass is proportional to the quotient p/v (for different bodies).

Then experiment will show that

$m_{in} \propto m_{gr}$.

We shorten this path insofar as we do not explicitly introduce the inertial mass. Rather, right from the beginning, we show that the proportionality factor (for a given body) in $p \propto v$ is proportional to the gravitational mass which is defined elsewhere.

Gravitational mass is formally introduced only after $p = m \cdot v$ has been dealt with. We consider this to be acceptable because students already have a clear idea about what mass is from the world outside of school. The reason for our choice of procedure is that we do not wish to introduce the relation $p = m \cdot v$ after first dealing with the special system "gravitational field".

We are inconsistent also in dealing with the relation $p = m \cdot v$. The "experiment" which is claimed to show the proportionality $p \propto m$ (one glider and a pair of identical gliders moving at the same speed) does not show unequivocally that $p \propto m$. Rather, it shows that p is proportional to any measure of an amount of matter because the gliders are identical not only in their masses m, but in the amount of substance n as well. An additional experiment can eliminate the possibility for $p \propto n$. However, we believe that the logical needs of our high school students are not so pronounced that they would be grateful for this kind of argument.

2. Momentum current distribution in fields

The path of a momentum current in a field is mathematically described by the distribution of the momentum current density (Herrmann, Schmid 1985; Heiduck, Herrmann, Schmid 1987). This is rather complicated. It is not discussed in class, just as we do not follow the path of the momentum once it has gone into the Earth. It is important that students come to the conclusion that the momentum flows somewhere. However, the exact path it takes is not of great interest. Incidentally, we know that the water in clouds somehow gets there from the earth but we don't necessarily know exactly which path it takes.

3. The word "weight"

Sometimes in our text we use the word "weight" as an everyday expression for what in physics is called mass, i.e., the quantity which is measured in kg. We do this in order to approximate as closely as possible the manner of expression normally used by non-scientists. We do not believe that students identify with the word 'weight' the physicist's gravitational force.

4. Literature

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5. Momentum and energy

1. Mistaking momentum for kinetic energy, and vice versa

A problem might be expected to arise for the student when kinetic energy is dealt with after momentum because they both depend upon the same variables m and v. Both the quantities momentum and kinetic energy grow monotonously with mass and velocity.

However, this problem will not emerge if the meanings of the two expressions are presented conveniently. This problem would certainly arise if one were to proceed as follows: "We introduce the two auxiliary quantities $\vec{p}$ and E_{kin} which are defined as follows: $\vec{p} = m \cdot \vec{v}$ and $E_{kin} = (m/2) \cdot v^2$."

The fact that this problem does not need to occur can be seen if the situation is compared to electricity. The relations analogous to $\vec{p} = m \cdot \vec{v}$ and $E_{kin} = (m/2) \cdot v^2$ are $Q = CU$ and $E_{field} = (C/2) \cdot U^2$.

Surely no one who has learned electricity in the usual way would confuse the quantity Q with E_{field} just because both grow monotonously with voltage and capacity. They are not confused with each other because a certain idea has been previously formed of each of them. Charge had not been defined by $Q = CU$, and field energy had not been defined by $E_{field} = (C/2) \cdot U^2$.

We proceed similarly in mechanics and generate an idea of energy as well as momentum before the relations $\vec{p} = m \cdot \vec{v}$ and $E_{kin} = (m/2) \cdot v^2$ are dealt with.

2. The bicycle chain

An interesting application of the relation

$P = v \cdot F$

is the transport of energy through the chain of a bicycle or motorcycle. However, we do not recommend using this example in class because it presents a problem that is best avoided at first, namely that the value of an energy current depends upon the frame of reference.

We suppose the bicycle moves to the right. If one considers the energy/momentum transfer in the bicycle's reference frame, then energy and momentum flow in the upper, taut part of the chain towards the rear chain wheel. Now if v_C is the velocity of the chain relative to the bicycle, and F is the momentum current in the taut part of the chain, then

$P = v_C \cdot F.$

The momentum flows back to the chain wheel in front through the (stationary) bicycle frame.

Using the Earth as the reference system, the taut section of the chain moves with the speed $v_B + v_C$, where v_B is the speed of the bicycle relative to the Earth. Therefore, an energy current of

$P_C = (v_B + v_C) \cdot F$

flows from the front chain wheel and through the chain to the one in the back. Since the bicycle is moving, there is a new energy current through the bicycle's frame:

$P_F = v_B \cdot F$

In our case, $v_B > 0$. There is compressive stress in the bicycle frame so the momentum current flows to the right, which means that the energy current also flows to the right. The total energy current flowing towards the back is the resulting difference

$P = P_C - P_F = (v_B + v_C)F - v_B \cdot F = v_C \cdot F,$

which is the same result as in the system of the bicycle.

3. The sign of the energy

In Section 5.2b, we found that the energy of a moving body (the portion of the total energy which physicists call kinetic energy) is always positive and independent of the direction of motion. It might seem obvious then to state that the physical quantity energy always has positive values. However, we have not formulated such a law because in certain areas of physics it is practical as well as common to adjust the zero point of energy so that negative energy values appear.

4. The content of energy storages

Section 5.2 deals with what in physics terminology are stress energy E_{spring} of a spring, kinetic energy E_{kin} of a body, and potential energy E_{pot} of a body. Each of these three contributions to the total energy are connected in a simple way with other quantities of whatever system is being considered:

$E_{spring} = (D/2) \cdot s^2$

$E_{kin} = (m/2) \cdot v^2$

$E_{pot} = m \cdot g \cdot h$

In our course, a minimal version has been chosen for dealing with these three expressions. In the first two cases, a storage system is simply assumed to exist. This means that the values of the quantities D and m which characterize the systems, are considered as given. The elongation s of the spring, and the velocity of the body v of the body are considered variables. The resulting theorem only contains the relation between E_{Spring} and s, or between E_{kin} and v, respectively. The only statement being made by this relation is that one quantity increases monotonously with the value of the other one. In the case of the third relation, the height h as well as the mass m are considered variables while g is considered a constant parameter which characterizes the energy storage. The relation between E_{pot} and h and between E_{pot} and m then appear as the theorem.

6. Momentum as a vector

1. Composition and decomposition of momentum currents

In order to discuss the vector addition of momentum currents, it makes more sense to begin with the composition of two currents, then with their decomposition. Two momentum currents merge and one wishes to find the current intensity after they merge. This is a simple problem.

On the other hand, it is always an ambiguous undertaking to decompose a momentum current. It requires arbitrarily setting directions.

2. The direction of a current and the direction of that which flows

One important difficulty in mechanics is based upon the fact that we must distinguish between two types of directions. In the force model these are:

– the direction of the force;
– the direction of the surface to which the force is related (A force is always defined relative to a surface)

In the momentum current model they are

– the direction in which the momentum flows;
– the direction of the flowing momentum.

This is a difficulty inherent to mechanics that cannot be avoided but might be alleviated.

Ropes are often used in mechanics to teach transfer of force because they represent the special case in which the direction of the current and the direction of the flowing quantity coincide. This procedure is unfortunate, particularly when the student does not perceive that this is only a special case.

In our approach, we deliberately begin the discussion of momentum currents in three-dimensional space with an example where the direction of momentum is transverse to the direction of the conductor. This way it is more easily seen that one must differentiate between the two directions.

The direction of the current is always the same as the direction of the conductor—exactly as in electricity. The direction of the flowing momentum can be identified by the way the momentum increases in the body into which it flows.

3. Momentum currents with the flowing momentum being transverse to the conductor

When a rod is used to transfer a force so that the force vector is transverse to the rod, the distribution of stress in the rod will be complicated. On one side of it will be compressive stress while on the other side there will be tensile stress. In the momentum current image, this means that not only momentum is flowing into one end and out the other (in Fig. 6.1, this is the *y* momentum) but another closed current of *x* momentum is flowing as well.

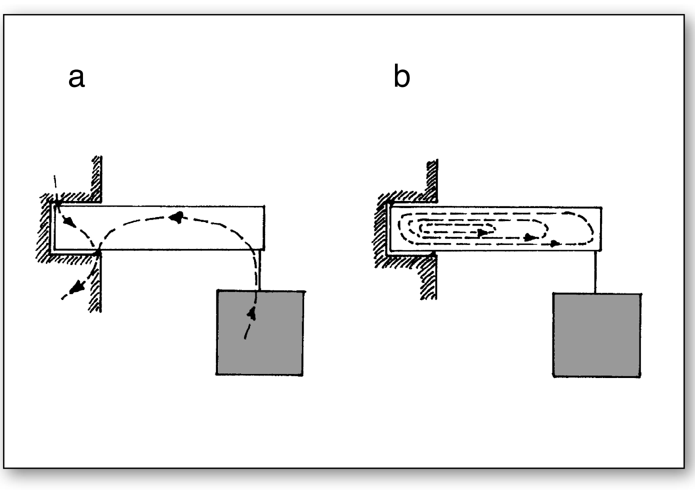

Fig. 6.1
(a) *y*-momentum flows through the rod from right to left.
(b) In the bottom part of the rod, *x*-momentum flows to the right, in the upper part it flows to the left.

In total, however, the current flowing through every cross section of the rod is only the net current flowing in one end of it and out the other. We do not discuss the additional circular currents because they do not contribute anything to the net current.

We do this with the same justification that is used for considering the water current in a river as only a net current. In fact, however, the current through a cross section transverse to the river is partly composed of opposing parts of currents, caused by eddies.

4. Addition of momentum current vectors

Three ropes with dynamometers (force sensors) built into them are commonly used to show vector addition of forces. The advantage of this method is that the forces are easy to measure. The disadvantage is that one deals only with the special case of force lying parallel to the device transferring it. In this case, the sides of the force triangle lie parallel to the momentum conducting connections (the ropes). A student might easily believe that this is always the case.

The fact that two other forces can be inferred from just one force—the summands can be clearly ascertained from the sum—shows that this is indeed a special case. This is, of course, only possible because the assumption is made that the vectors lie parallel to the ropes.

If forces are transferred through rigid conductors, rods for example, this assumption can no longer be made. Force can no longer be unequivocally decomposed into parts.

5. Momentum conductivity in three dimensions

After introducing electric currents, it is logical to ask which objects or substances conduct electricity and which do not. In mechanics, it is just as logical to ask which objects or substances conduct momentum after the subject of momentum currents is introduced. However, the answers to questions about conductivity are more complicated and interesting with momentum than with electricity due to the vectorial character of momentum.

There are several simple observations of mechanical phenomena which lend themselves to a description in terms of momentum conductivity. For instance, the wheel of a vehicle serves not only to insulate momentum (as we had formulated in our one-dimensional treatment of momentum). Rather, a wheel does not conduct the momentum of a certain direction (lengthwise to the vehicle) whereas it transfers transverse momentum into the Earth.

It becomes even more interesting when rotational processes are taken into account. It is easy to build a device which is a conductor for angular momentum, but an insulator for linear momentum, or vice-versa. A worthwhile subject might be a discussion of the different components of a Cardan shaft.

6. The symbols $\vec{p}$ and *p*

We do not use the normal *p* as a symbol for the magnitude of vector $\vec{p}$, but as the symbol for the momentum if we are dealing with momentum in just one direction. In this case, *p* can be considered as the only component of $\vec{p}$, different from zero. Therefore, *p* can take positive as well as negative values.

7. Components of momentum

There are two alternatives for dealing with the vectorial character of momentum.

(1) An *x-y-z* coordinate system is introduced right at the beginning and momentum is always dealt with in terms of its components. The balances for the *x*, the *y*, and the *z* components are made individually. The advantage of this approach is that one deals with three conservation laws independent of one another. Each momentum component can be treated as a scalar. The disadvantage is that a problem becomes convoluted when one momentum conductor, a rope for example, runs at an angle to the axes of the coordinate system. When this happens, several momentum currents flow in the conductor at the same time. For instance, in a rope lying in the *x-y* plane, but not parallel to the *x* or the *y* axis, *x* and *y* momentum currents flow simultaneously. These currents can even flow in opposite directions. Because of these complications, we have decided for the second method below.

(2) Momentum is represented by an arrow. Each direction characterizes a particular type of momentum. The number of types of momentum is infinite. In the text we characterize these kinds of momentum by indicating the angle of the arrow representing the momentum vector, with respect to the positive *x* direction. We can then say, for example, that 45-degree-momentum is flowing in a rope.

7. Torque and center of mass

1. Ropes and pulleys

A rope running over a pulley changes its direction. It would seem logical then to assume that the momentum current flowing through the rope changes its direction as well. The corresponding expectation can also be enunciated in “force mechanics.” One might believe that the pulley diverts a force. The fact that this is not so must be carefully developed in class. A momentum current can, of course, be change its direction – just not with a pulley. When the direction of a momentum current is changed, the current vector retains its direction.

2. The law of the lever

We have deduced the law of the lever from experiment. It would probably have been more logical to first introduce angular momentum and then to derive the law of the lever from it as a special case of angular momentum conservation. We suppose, however, that in many cases, one does not introduce angular momentum, but does wish to deal with the law of the lever.

8. Angular momentum and angular momentum currents

1. Torque and angular momentum current

Just as the quantity $\vec{F}$, which is traditionally called force, can be interpreted as the strength of a momentum current, torque $\vec{M}$ can be perceived as the strength of an angular momentum current. For the time derivative of the angular momentum $\vec{L}$ the following well-known equation is valid:

$$\frac{d\vec{L}}{dt} = \vec{M} ,$$

a balance equation analogous to

$$\frac{d\vec{p}}{dt} = \vec{F}$$

or to

$$\frac{dQ}{dt} = I$$

However, dealing with $\vec{M}$ as angular momentum current is rather complex.

It is easy to understand that angular momentum flows in a rotating shaft that drives something else. However, it is more difficult to see what path the angular momentum current takes when a wheel is driven by a belt. It is impossible to localize the angular momentum current in this and in many other examples. No current density field can be given.

To avoid this difficulty, we have introduced torque as an independent quantity.

2. Energy transfer with angular momentum

In analogy to the relation

$$P = \vec{v} \cdot \vec{F}$$

which can be used to calculate the energy current through a drive belt, the following is valid for energy transfer through a rotating shaft

$$P = \vec{\omega} \cdot \vec{M} .$$

Although this relation is very useful for a discussion of drives, we will not be introducing it. If we were to do so, it would also be necessary to introduce angular velocity and the radian measure, for which there is not enough time in this course. In addition, it would be desirable to have a handy device for measuring torque, which we do not have either.

9. Compressive and tensile stress

1. The three principal stresses

The scalar quantity “pressure” results, under special conditions, from the tensor representing “mechanical stress.” Mechanical stress is a second order tensor. In friction-free fluids and gases, the diagonal elements of the tensor matrix are equal, all other tensor components being zero. Such a tensor can be described by a single number, i.e. the value of the diagonal elements. It is this quantity that we call pressure.

It is not difficult to get an intuitive idea of the mechanical stress tensor. A tiny element of matter inside a body can be under three independent tensile or compressive stresses in three perpendicular directions. In order to describe the state of stress at the location of the element, six numbers must be given:

– three numbers to describe the orientation of a right angled trihedron;

– three stress values belonging to the axes of the trihedron.

The directions of the three axes are called principal directions.

In the special case of fluids and gases, the three stresses are equal. Particular directions need not be given because all directions are equivalent.

Another special case is obtained when the stress is different from zero in just one direction. This case appears in most applications of mechanics typically taught before hydromechanics: When force is transferred by a rope or rod (as long as the force vector lies parallel to the rod). To describe such a state of stress, it is enough to specify just one direction and just one compressive or tensile stress.

In most realistic situations, the stress tensor has its most general form. Three numbers are needed to describe the principal directions and three for the corresponding stresses. The stress of the wood of a laden tabletop is an example.

2. The isotropy of the hydrostatic pressure

One of the objectives of this approach is to show that the pressure in friction-free fluids and gases is isotropic. In order for students to grasp that this is a peculiarity, they must first get to know the normal case. They must see that normally pressure is not isotropic. This means that they must understand that an object can be under different pressures in different directions.

It is easy to understand that a solid body can be exposed to various pressures in various directions. However, it is rather more difficult to grasp that there are only three independent directions. This is also difficult to demonstrate in a classroom, because the experimental material is usually not available.

3. Hydraulic energy transfer

In our opinion, one aspect of hydraulics is often dealt with unsatisfactorily. The main reason hydraulic installations are so common is that they transfer energy in a convenient way. This is why hydraulic energy transfer plays a more important role in our approach, than in traditional ones.

10. Entropy and entropy currents

1. Entropy right from the beginning

Entropy and temperature play the same role in thermal processes that electric charge and electric potential do for electrical processes and momentum and velocity do for mechanical processes. Entropy, electric charge, and momentum are extensive quantities. Temperature, electric potential and velocity are the corresponding intensive "energy conjugate" ones. This comparison indicates why entropy is as important to thermodynamics as electric charge is to electricity and momentum is to mechanics. Entropy currents also play as important a role in thermodynamics as electric currents do in electricity and forces (momentum currents) do in mechanics. It would therefore be consistent to begin with entropy when teaching thermodynamics. Thermodynamics without entropy is only a makeshift approach.

2. The state variable entropy as a measure of heat

There is a widespread belief that entropy is difficult to understand. This is certainly the case when it is introduced as Clausius did. It may be easier to understand entropy when introduced statistically, as a measure for the microscopic disorder of a system. However, this approach is not very useful for solving practical problems.

We have therefore chosen a third way to introduce entropy. This approach is founded upon work done by Callendar (1911) and described and substantiated in detail by Job (1972) and Falk (1985). It is based upon the idea that the characteristics of the physical quantity entropy correspond very well with the every-day concepts of "heat" or "amount of heat." There are only few other physical quantities for which we have such a good experience from everyday life.

Unfortunately, we cannot use the word "heat" for the quantity S, because this word is already being used elsewhere in physics. It is used (but not uniformly) to indicate the differential form $\delta Q = TdS$. It is difficult, if not impossible, to understand what such an entity expresses. The Q behind the differential sign δ is not a physical quantity. Sometimes this is expressed by saying that Q is a process quantity. Entropy and energy, on the other hand, are said to be state variables. This gives the impression that a state variable is the exception. In fact, all quantities of physics are state variables with only two exceptions: heat and work. It is so common to see a quantity as a state variable that no one usually thinks about emphasizing this. The unfortunate and –seen from a modern viewpoint– superfluous construction of the entities called heat and work often leads to confusion not only for students, but for physicists as well.

In this book, we do not operate with "work" in dealing with mechanics and, correspondingly, we will not use the "process quantity" Q in thermodynamics.

3. Large and small thermal effects

The decision to introduce entropy at the very beginning of thermodynamics opens up the possibility of reassessing the subjects covered in teaching thermodynamics. The phenomena, facilities and systems in which entropy currents play an important role, such as heat engines, heating systems, heat pumps or the Earth's heat balance are put in the foreground. We omit other phenomena which are traditionally discussed in teaching thermodynamics. One example is thermal expansion of solid bodies, an effect of the order of of 10^{-4}.

4. The temperature scale

Unnecessary problems are often created at the school as well as the university level, when defining the temperature scale. One begins by defining a scale based on the expansion of mercury, then proceeds to a better definition using the expansion of gases, and finally arrives at the standard thermodynamic scale.

If we follow the historical path we create the impression that defining a temperature scale is a particularly difficult problem. Indeed, one could proceed in the same way with any other intensive quantity, but obviously nobody would do so.

The fact that one does not begin with the thermodynamic scale (the simplest to conceive of) is the result of trying to postpone or avoid the introduction of entropy at all costs.

5. Misperceptions

There are subjects which have almost become ritualistic. Measuring temperature is deemed necessary because our sense of temperature can so easily be deceived. This kind of misperception is an interesting subject in itself. However, misperceptions apply to all other perceptions as well: Perceptions of light and dark, height, distance and speed as well as time, force, mass, sound intensity and pitch. These so-called "misperceptions" actually have important and positive functions and are not simply a deficiency of our sense organs. The subject of "misperceptions" should be a part of the teaching of physics, but the discussion should not be limited only to the example of temperature.

6. Observation and explanation in experiments

Our approach to discussing many experiments is to first describe what is being *observed*. This description in a statement about *temperature* might be, for example: "The temperature of the water in container A decreases and the temperature of the water in container B increases." Then we ask for the *explanation* of this. In so doing, we are asking for what the *entropy* is doing in this process. "It goes from A to B" would be the answer. Compare with Remark 9 in Chapter 3.

7. Which are the processes with the highest entropy production?

There are misconceptions about which processes produce a lot of entropy and which ones produce only a little. The most important entropy producing process on Earth is the absorption of sunlight.

8. Literature

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11. Entropy and energy

1. About the meaning of the materials property "specific heat capacity"

Entropy capacity and specific entropy capacity which replace specific heat do not play a major role in our approach. The dependency of the specific entropy capacity upon the material (just like that of specific heat) is very slight when compared with other property values such as electric conductivity, thermal conductivity, density, and optical properties. The material dependency of the entropy capacity becomes even smaller when it is related to the amount of substance instead of mass. Furthermore, there are hardly any phenomena which depend upon the difference between the specific heat capacities of different substances. The rationale of the difference between land and sea climates, which is sometimes quoted, is unfounded. The fact that more entropy is stored in sea water than in the solid rocks of land is the result of the constant motion of the water which causes a much better transport from the surface to the deeper layers than is possible on land.

2. Ideal heat pumps

We assume that heat pumps work without loss, meaning that no entropy is produced in them. This is done with the same rationale as when discussing lossless electric motors, transformers or purely mechanical machines.

3. "Thermal friction"

The fact that entropy is produced in the experiment described in section 11.3, Fig. 11.7, is based upon a simple and convincing calculation. However, it is not actually worthwhile carrying out this experiment. We have no method for measuring entropy currents which is as simple as that for measuring electric currents. Measuring energy currents would be difficult enough, but is not worthwhile because what makes the effect interesting, namely the increase of entropy, would not even be visible.

To convince students that entropy does increase, an effect would need to be shown whereby something warms up. However, in the "experiment" in section 11.3, the entropy current is stronger at the cold end of the rod, i.e. where the temperature is lower. This is not a contradiction. One only needs to imagine that the flow velocity of the entropy here is greater than at the warm end.

The only case known to us in which the entropy produced by "thermal friction" has been detected directly is the gas oscillator in the PSSC course (1974). In this experiment, the damping of a mechanical oscillation is the result of thermal friction. Unfortunately, it is hardly possible to build this experiment without a well-equipped workshop.

It is easy to imagine a variant of the PSSC experiment where thermal friction actually leads to a rise in temperature. The trick is to press the entropy of a gas through a heat resistor several times. The necessary temperature gradients are obtained through repeated isentropic compression and expansion of the gas.

4. Entropy content and heat content

When dealing with subjects that are related to specific heat, heat of vaporization, and heat of fusion, entropy has special advantages because it is a state variable as opposed to the traditional "quantity of heat." It can play the role of an actual heat content. In our approach, it is the entropy *content* which is primary, and *changes* of entropy are considered as differences of entropy contents. This holds for processes related to temperature changes, as well as for phase changes.

It is not possible to deal with the energy form called "quantity of heat" in this way because there is no heat content which is based upon this quantity. Here, one can only speak of adding heat or removing heat: Heat added per temperature interval or heat added during a phase change. According to our experience, students believe that the quantity Q can be contained within a body. The popular mixing experiments support this misunderstanding.

5. Entropy values

Many physicists and physics teachers view entropy with suspicion because they do not have a feel for the values of this quantity. Chemists do not have this problem. Their Chemical Tables show, along with heat capacity and enthalpy of formation, the values of other quantities such as entropy (usually given per mole) for a chemical under normal conditions. For some of the more important chemicals, the values of all these quantities are even given as functions of temperature from $T = 0$ K up to several hundred Kelvin and across the various phases. We recommend that teachers of physics find out how convenient it is to use such tables.

6. Advantages and disadvantages of the traditional quantity of heat

The following arguments in favor of the traditional "quantity of heat" could be put forth:

1. It is easy to analyze mixing experiments if energy balances are made because the energy remains constant while entropy is created. The amount of entropy after the mixing process is therefore greater than before.

2. Within a large temperature range, the specific heat remains constant. This means that it remains independent of temperature. However, the specific entropy capacity, which results from specific heat by dividing by the absolute temperature, is temperature-dependent.

We believe that the disadvantages presented by entropy are not serious compared to those which arise when dealing with the non-state variable quantity of heat.

We can avoid the first of these two problems by simply not allowing very large temperature differences to appear during mixing. As a result, the amount of entropy produced is small compared to the amount transferred.

The second advantage of energy over entropy mentioned is not fundamental. After all, traditional specific heat is temperature independent only in a limited temperature interval. It is somewhat more complicated to perform calculations with specific entropy capacities than with heat capacities, but for many problems, it suffices to take an average value for it.

7. Literature

PSSC: Physik. S. 380. Friedrich Vieweg & Sohn, Braunschweig (1974).

12. Phase transitions

1. Phase changes as chemical reactions

A phase change is a special kind of chemical reaction. It is when a single starting substance transforms into a single product. It might easily be believed that the chemical potential would be ideal for dealing with phase changes, and in general this is true. However, transitions between the solid, fluid and gaseous state constitute an exception because they normally take place uninhibited. This means that the chemical potential differences between the phases are always zero, the phases are in chemical equilibrium. Therefore, the chemical potential as a variable never even appears.

2. Entropy and enthalpy

When energy rather than entropy is introduced first, problems are encountered. They become particularly manifest when treating evaporation. When, for instance, water is heated and vaporized by an immersion heater, the energy emitted by the heater is not fully supplied to the steam, as students might expect. Part of this energy is needed to "push away the atmosphere." On the other hand, this expectation is actually fulfilled by entropy. The entropy coming out of the immersion heater all goes into the steam. Traditionally, this situation is described by saying that the energy emitted by the immersion heater causes an equal change of the enthalpy of the water. Enthalpy is a state variable, but despite this, it is not appropriate for school, especially for the beginner because it is not substance-like. There are no enthalpy currents and it makes no sense to talk about conservation or non-conservation of enthalpy.

13. Gases

The relation between *S*, *V*, *T* and *p* in Gases

Gases are interesting from a thermodynamic viewpoint because the thermal variables S and T are coupled to the mechanical variables p and V. This coupling is expressed, for instance, in the coefficient of thermal expansion

$$\alpha = \frac{1}{V}\frac{\partial V(T,p)}{\partial T}$$

which is very large. This is the reason why it is possible to construct heat engines with gases, and it is also responsible for many weather phenomena.

The quantitative relationship between the four variables mentioned above is too complicated to be dealt with in middle school. One reason is that a logarithm or exponential function appears in it. An even greater complication is simply the fact that there are so many variables participating.

Of course, it would be possible to limit oneself to the quantitative treatment of partial relationships, such as Boyle's law. However, this law is not very interesting because it describes isothermal processes. Isentropic processes are much more interesting.

We suggest choosing a version in which the interplay of all four variables can be considered, although only qualitatively. This interplay can be demonstrated easily in experiments and students can develop a feeling for how the four quantities change their values in different processes. They do not need to memorize the relations compiled in Fig. 13.9, but rather should be able to rediscover these rules for themselves through the feeling they develop for gases.

14. Light

The thermodynamics of light

In Chapter 14, some subjects are covered which belong to the area called “Thermodynamics of Light.” Light is a system which is of vital importance to the heat balance of the Earth. Unfortunately, its thermodynamics is so different from that of material gases, that it can only be discussed in a limited way.

As long as light is in a radiation cavity, meaning inside a container, it is well behaved. Problems arise when it leaves the cavity and forms rays. This flowing light has no rest-reference system. This is the reason for its unusual thermal behavior.

One of these peculiarities is that the relation between the energy current and the entropy current is no longer:

$P = TI_S$,

but

$P = (3/4)\,TI_S$.

Here P and I_S are the energy and entropy currents, respectively, coming out of the radiating object and T is the temperature of the object itself.

Another anomaly: Thermal light coming from the Sun continually takes up more space. Neither the entropy nor the temperature of the light change during this process of expansion. This is not an expansion process in the usual sense of thermodynamics. A good example for a true expansion process of light is expansion of the cosmic background radiation associated with the expansion of the universe. This is an isentropic expansion in which the temperature drops, just as it does with a material gas.

The subjects covered in Chapter 14 are chosen to avoid these problems because delving into these questions would take too much time.

15. Data and data carriers

1. Contents of a teaching unit about data technology

Information or data technology plays an important role in just about every aspect of life today. Many technical devices found in homes serve to transport or store data: Smart phones, televisions, DVD recorders and players, video recorders and players, cameras, projectors, etc. There are public services for data transfer such as the internet, telephones both mobile and with land lines. The mail serves this function too. Books and newspapers serve to transfer news and information as well as to store it. Data is transferred by copper cables, fiber optic cables, radio link systems, and via satellites. Observational techniques such as radar and sonar are also part of data technology. Every data acquisition process is basically data technology. Medical diagnostic methods are data technology. This is especially apparent with modern diagnostic methods such as tomography.

Of course, one of the most important devices of data technology is the computer.

The transfer, storage and processing of data is also of great importance in biological systems. Our sense organs serve as data acquisition devices. The nervous system transports data and the brain processes and stores them. In turn, gestures and language emit data. The data "technology" of biological systems takes place to an even greater extent at the molecular level.

These phenomena, technical devices and methods have something in common: They all have to do with data transfer, storage and processing. One does not need to be an expert to recognize that all this has something in common.

It might be expected that these commonalities would lead to a unified scientific description, a description with a universal structure. Unfortunately, this has not been the case. Instead, a series of individual disciplines has emerged. Among these are optics, acoustics, electronics, metrology, communications engineering, computer science, and others. Two of these subjects, optics and acoustics, have become sub-areas of physics. Some special methods from other areas such as electronics or communications technology have found their way into physics teaching. Yet another part of data technology is dealt with in biology.

Classification of individual branches of data technology into totally different sub-disciplines, which has partly been done using relatively superficial technological considerations, has a disadvantage. There is no recognizable unified structure in data physics.

In the long run, school teaching cannot afford to simply add or insert a new development somewhere into it. The range of subject matter is so comprehensive that it cannot be modernized in this way. When developing a curriculum, the question must constantly be raised of whether what is new allows an integration into or a synthesis with the old and if the old and the new can be dealt with together. One must also ask whether subjects which appear different are possibly just special cases of one and the same thing.

Looking for superordinate aspects is not only desirable for learning economy. A curriculum which is based upon technical aspects is very susceptible to becoming outdated. Here is an example: When computers are discussed in class, the current construction of computers is what is talked about. As an electronic device, it is categorized under the subject of electricity. Nevertheless, it should be considered whether there are things that can be said about computers that are independent of their technical realization. Nowadays, a computers works electronically. However, they could actually work mechanically as well, and one day, they will function optically. The brain is a kind of electrochemical computer.

For this reason, one should try to find ways of making essential statements about computers without taking into account their current construction. For example, the brain is built very differently from present day computers, and computers with multiprocessor architecture or computers using the architecture of neural networks are becoming increasingly important.

It should also be possible to make statements about computer activities which are independent of the kinds of problems being solved by it: whether it is solving a differential equation, recognizing a pattern or working as a process computer.

For this reason, we emphasize the common structure of various phenomena, methods, and devices of data technology.

On the one hand, economy of learning is a reason for pursuing this goal. On the other, the fact that these commonalities exist is, in itself, an important teaching objective.

2. Shannon's measure of the amount of data

An appropriate tool is necessary for describing all the phenomena and technical devices associated with data technology from a unified physical perspective. The most important tools of a physicist are physical quantities, so we need a quantity which can be used to describe the phenomena mentioned in the last section.

Our situation is similar to that of the middle of the 19th century. At that time, the scientific descriptions of mechanics, electricity, and thermodynamics were fairly independent of each other although it was clear even then that relationships must exist. These relations could be described by theory only after a new physical quantity was constructed: the energy.

One of the reasons that energy has attained such importance is that it is *substance-like*.

Given the success that introducing energy has brought physics, it would be desirable to construct a quantity with a substance-like character that allows a unification of different areas of data technology. We are fortunate enough to already have such a quantity. It is the measure of the amount of information or data introduced by C. Shannon (Shannon, Weaver 1949).

This quantity is well established in communications engineering. It has also become the central quantity of information theory. Unfortunately, the possibility it presents as an aid in systematically organizing data technology has, to date, not been taken advantage of.

The Shannon measure of information, or amount of data, is defined as

$$H = -\sum_{i=1}^{N} p_i \text{ ld } p_i \text{ bit}$$

This quantity is a measure of the amount of data (measured in bits) carried by one symbol. N is the total number of symbols used. p_i is the probability of appearance of the symbol with the number i. "ld" stands for the logarithm with a base of two. The equation calculates the amount of data contained in a storage unit as well as the amount of data transported through a conduit in a given interval of time.

At first glance, it appears that this quantity is too difficult for elementary teaching. It appears to assume a prior knowledge of logarithms as well as probability. However, on closer examination, one sees that there is a simpler version of the expression for H, which makes the handling of this quantity particularly easy.

For now, only processes where all N symbols appear with the same probability will be discussed, so

$$p_1 = p_2 = \ldots = p_N = 1/N.$$

Then the defining equation simplifies to

$$H = \text{ld } N \text{ bit}$$

No probabilities appear in this expression but it does contain the logarithm. Because the last equation is equivalent to

$$2^{H/\text{bit}} = N,$$

even students who do not yet know logarithms can easily determine the value of H. They only need to find out which power of two is closest to N.

We have now arrived at a characteristic of the amount of data which makes it an easily accessible quantity. While the values of other quantities are often only obtained through complicated methods of measurement, the value of H can basically be found by counting.

Another reason why dealing with the quantity H is not difficult is its substance-like character.

3. "Information" or "amount of data"?

Shannon called the quantity H the "entropy of an information source." Soon after this quantity was introduced, another name became more and more widespread. Many authors called it simply "information." In the following, we will explain why this choice of a name is unfortunate.

First, we have to note that the word information is not used uniformly in scientific literature. The name "information" for the quantity H is mostly found in books about information theory. In computer science, by contrast, information is understood to be something else. The nuanced definition of the word varies from author to author. Here, the word means a single message. It is *not* the name of a physical quantity.

We consider the use of the word "information" for describing the quantity H to be inappropriate because it inevitably causes wrong associations. "Information" is an everyday word and the everyday definition is no help in understanding the physical meaning of the quantity H, but is a hindrance instead.

The definition of the word "information" in everyday language deviates from that of the quantity H in several respects. This can be seen in the following sentence which makes sense in colloquial language: "He gave me an important piece of information about some procedures."

In this case, the word information means just a single message. This sentence is not describing a number or amount of messages.

In addition, the adjective "important" is used here to describe the information according to human and not physical criteria. The only time it makes sense to use everyday language when describing information is when the last link in the chain is a person. The quantity H does not allow for a valuation in human terms. It also does not matter whether or not a person participates in the transfer of the information.

The sentence also shows that when speaking colloquially about information, one always gets information *about* something. This situation can be expressed more formally: System A receives information from system B about system C. Now if the word information is used for the quantity H, this situation leads to some odd ideas about exactly what the quantity H is referring to. In fact, as a substance-like quantity, H is attributed to a physical system. If one has a current of H in mind, a second system can come into play. One might say that a current flows from system B to system A. Bringing a third system C into it makes no sense here.

The name "amount of data" which we propose does not have this disadvantage. It is formed from the analogy to the name "amount of substance" for the quantity n. The word "amount" refers to the fact that not just a single message is meant. This could be texts, pictures, etc., in short: data. The word "data" emphasizes the fact that the contents of the communication are unimportant. Schopenhauer called the signals sent through the sense organs to the brain "data" for this same reason.

The word data as a part of the Shannon measure also has the advantage of suiting the large amount of terms in computer science and data technology which contain the word "data." One speaks about data transfer, data processing, data storage, data networks, data intake and outflow, data banks, etc. It sounds much more natural to say "The storage unit contains a lot of data" than to say "The storage unit contains a lot of information."

4. The meaning of a message

The attempt is sometimes made to differentiate between "communication with its meaning" and "communication without its meaning". This is done by Weaver (Shannon, Weaver 1949) by speaking of "communication" in the first case and by referring to a "signal" in the second.

The need for such a differentiation exists only when a person is the intended receiver of the communication. It makes no difference at all for the physical description of a transport of data whether or not there is a person involved. In addition, the distinction between data with or data without meaning probably leads more to confusion than to clarity.

5. The accuracy of a number of bits

The formula used for calculating H has a pleasant characteristic: The value of H is rather insensitive to errors in the quantity N. In spite of a great uncertainty in the numbers of signs, the results for H are rather exact making it often not worth the effort of finding the exact value for the number of signs.

6. What is an "amount of data" attributed to?

The usual treatment writers give Shannon's measure of data sometimes causes confusion. Exactly what the value of the quantity should be attributed to is often not well expressed. The quantity H is mostly called "information" and one often finds statements of the following type: "The information about this situation is...", or "The information about the system missing for the observer is....".

H is a physical quantity, and like every other physical quantity, it belongs to a physical system—not to a situation or to an observer. Nonetheless, the value of a quantity can depend upon the observer, or more exactly, upon the frame of reference chosen by the observer. For instance, the momentum of a car depends upon the frame of reference used to describe the motion. This does not, however, change the fact that it is the car's momentum being dealt with and not the momentum of the frame of reference or of the observer.

Therefore, in the classroom, one should always use the words amount of data in such a way that it is clear in which system the data, the amount of which is being discussed, is contained or from which system to which system it is flowing.

Data can flow to a person and be stored there in his or her brain. In this case, the person does not play the role of the observer, but of a normal physical system. A person can also have momentum, and here as well, the person is not the observer, meaning the one who determines the frame of reference.

7. Taking profit of the additivity

When we calculate an amount of data, we often take profit of the additivity of H, however without expressly letting students know this. For example, the amount of data on a rasterized image needs to be calculated. The image has $20 \cdot 20 = 400$ pixels and each pixel has one of four color values, black, dark gray, light gray, or white. One way of calculating the amount of data in the image is done through the total number of signs. This means that the number of all possible images which is 4^{400}. It is not easy to make clear to students how this power is obtained. In addition, the value of N is very high and is beyond what we have in our Table of powers of two.

Therefore, we proceed differently. It is easy to see that the amount of data of one pixel is 2 bits. Because of the additivity of H, the result for the entire image is:

$$H = 400 \cdot 2 \text{ bit} = 800 \text{ bit}.$$

If students could use logarithms, the result could be calculated differently:

$$H = \text{ld } (4^{400}) \text{ bit} = 400 \cdot \text{ld } 4 \text{ bit} = 800 \text{ bit}.$$

8. Redundancy

A binary code is called redundant when one sign has less than one bit, meaning that both possible signs are not equally probable. Data transport with signs of non-equal probabilities will be dealt with later on and so will be the phenomenon of redundancy.

9. Literature

HERRMANN, F., SCHMÄLZLE, P.: Daten und Energie. J. B. Metzler und B. G. Teubner, Stuttgart (1987).

SHANNON, C. E., WEAVER, W.: The mathematical Theory of communication. University Press, Urbana (1949).

16. Electricity and electric currents

1. Should static or flowing electricity come first?

At the beginning of the subject of electricity, the question arises of where to begin. Should electric currents be dealt with first, or should electrostatics? Teaching would be easier if this question did not need to be asked.

If one wished to describe the properties of water to a hypothetical person who had never seen a fluid before, one would never come up with the idea of limiting the explanation to either flowing water or accumulated water at rest. One would immediately demonstrate that water can be stored in a container and that it can flow from one place to another.

In thermodynamics, we consider the entropy stored in a body as well as entropy currents. In the field of mechanics, it is a good idea as well, to deal with momentum and momentum currents (forces) in parallel.

Why shouldn't this be possible in electricity? Because nature is such that electric currents only clearly manifest in experiments where electricity does not accumulate. The amount of accumulated electricity in electrostatic experiments is so small, that currents are very difficult to detect. The methods used for detecting electric currents flowing for very short time spans only (with a glow lamp, for instance) are totally different from those for detecting "proper" currents (which is done by their heat production or their magnetic fields).

On the other hand, strong electric currents of the magnitude 1 A, which flow over a longer time period, are not associated with a net charge of any particular body or device. The electric charge of all components participating is practically zero.

For this reason, electric phenomena decompose into two classes with only a few points of contact.

We have decided to begin with the phenomenon every student has had practical experience with: Electric currents. This results in discussing something that flows and which we do not encounter in its non-flowing state. We speak about properties of electricity that only appear when it flows and not the characteristics of static, non-flowing electricity.

In this approach it seems that static, non-moving electricity has no properties at all. At first, students do not learn that the properties of static electricity in a wire are unnoticeable because the effects of positive and negative electric charge (the fields) cancel each other out.

In order to form a clear idea of electric currents, we call that which is flowing by name right from the beginning: Electricity or electric charge. In addition, to emphasize that the unit Ampere measures the strength of the current, we reiterate that Ampere is only an abbreviation for Coulomb per second.

At this point, accuracy counts. It is all too easy to mistake current for voltage or potential. Such mix-ups are supported by expressions like "There are 200 volts of electricity", which every student has heard.

When we say that there is electricity flowing in a wire or if we simply speak of the electricity in a wire, we mean only the mobile part of the total electric charge. At the beginning of teaching electricity, we avoid speaking about the fact that electricity can have two signs. In particular, we wish to avoid speaking about the motion of the charge *carriers*. This is because the charge carriers often move in the opposite direction of the electric current only resulting in unproductive discussions of signs and directions.

2. "Electricity" or "electric charge"?

We use the words electric charge (or just charge) and electricity as synonyms. However, at the beginning we prefer the word electricity. In everyday language, the word charge makes us wonder exactly what is charged and we do not want to go into the question of charge carriers at the beginning of the subject of electricity. In addition, at an earlier point in this course we spoke about charging an energy carrier with energy. Although not expressed exactly like this, energy appeared there in the form of a charge.

We will only introduce the word charge for the quantity Q when charge carriers are discussed.

3. Electric potential and voltage

We will introduce electric potential before electric voltage. This means that we will only discuss the differences of values of a quantity when the quantity itself has been introduced (Herrmann, Schmälzle 1984).

The problem which arises when voltage is discussed first, or when the discussion is limited to voltage, is well known to most teachers. Students attempt to assign a voltage to a particular point of the electric circuit.

It is therefore useful to emphasize in class that when a sentence has the word "voltage" in it, the preposition "between" or "across" should actually also appear. While it is possible to say, "The potential of this wire is..." it must mean, "The voltage *between* these two wires is...".

Operating with electric potential is what has made using color-coded conductor sections possible.

4. The zero point of potential

One problem that is encountered when working with electric potential is that the potential values of various locations on a non-grounded electric circuit are unknown and depend upon influences which are difficult to control. In order to have well-defined conditions in the classroom, we always ground our circuits.

5. Junction rule and loop rule

The junction rule and the loop rule are of great value in calculating electric networks. Their scope of application is very large. Unlike Ohm's law, they are not dependent upon the characteristics of a material. For this reason, they play an especially important role in our course.

It is not really necessary to explicitly formulate the loop rule. Students use it automatically when working with electric potentials. If a potential is associated with every point of a circuit, it follows that the potential differences between the ends of all sections of a loop add up to zero.

The junction rule is a special case of the balance equation for electric charge:

$$\frac{dQ}{dt} + \sum_i I_i = 0$$

If the charge inside a spatial area does not change, we have:

$$\sum_i I_i = 0$$

This means that the total current through the surface equals 0 A. Therefore, the junction rule is valid for a spatial area (which contains the junction), as long as the value of the charge there does not change.

The loop rule is a special case of Maxwell's second equation:

$$\oint \vec{E}\, d\vec{r} = -\iint \dot{\vec{B}}\, d\vec{A}$$

If the magnetic flux through a closed path does not change in time, we have:

$$\oint \vec{E}\, d\vec{r} = 0$$

This means that the contour integral over the electric field on this path is equal to zero. The loop rule is valid as long as the magnetic flux through the loop of the network in question does not change.

6. Ohm's law

Ohm's law will be observed twice on two separate devices within the framework of this course. First, on an arbitrarily chosen piece of wire (whose temperature may not change much when an electric current flows through it) and second, on technical resistors.

The fact some arbitrary wires follow Ohm's law is not important to most of the questions we will go into. Ultimately, we almost always assume that the resistance of a wire can be ignored.

Although the fact that a technical resistor follows Ohm's law is important, it does not give any insight into nature because they are constructed to follow Ohm's law in order to have an ohmic characteristic curve.

7. Characteristic curves

When measuring a characteristic curve, we emphasize that the voltage is the independent variable, meaning a variable which we can arbitrarily change. We therefore normally do not use a voltmeter but read the voltage on the setting dial of the power supply unit.

Of course, we could give just the opposite impression—that we arbitrarily set the electric current and then read the voltage. One only needs to use a current stabilized device (instead of a voltage stabilized one). We do not do this because we have decided to interpret the electric potential (generally the difference of the values of the intensive variable) as a "driving force" or "cause".

8. Parallel and series connections of resistors

Parallel and series connections of resistors only appear here in exercises and only identical resistors are combined in these exercises. The corresponding rules are not included in the list of important laws. The reason for this is that devices with ohmic characteristic curves are special cases. Therefore, the scope of application for the combination rules is limited. Moreover, when discussing these rules it would be logical to discuss also the corresponding laws for other currents such as momentum, entropy and water currents. This is never done because the subject is considered too unimportant.

9. Literature

HERRMANN, F., SCHMÄLZLE, P.: Das elektrische Potenzial im Unterricht der Sekundarstufe I. MNU 37/8, 476 (1984).

17. Electricity and energy

No remarks

18. The magnetic field

1. Fields as concrete entities

It is important to introduce fields as physical systems to be taken seriously. This corresponds to modern field theory and is easy to understand (Herrmann 1989, 1990).

Maxwell (1954) defined in 1873 electric fields as "...the portion of space in the neighborhood of electrified bodies, considered with reference to electric phenomena." The formulations used today for defining fields remind us strongly of Maxwell's definition. The field is often described as a *spatial area*, in which something happens or in which certain forces are acting.

Such a description is difficult to understand nowadays. In Maxwell's time this was different. Maxwell and his contemporaries imagined space to be filled by a kind of medium called the ether. Space and ether were taken to be identical. The field therefore was a special state of this medium. Since the ether has been banned from physics, Maxwell's description has lost its vividness.

2. Magnetic and electric action at a distance

Formulations such as "like poles repel each other and opposite poles attract each other" come from the pre-Faraday time, a time when interaction was described as action at a distance. Although no scientist has believed in such interaction for over a hundred years, the old formulations are still used which just encourages the old point of view.

The description mentioned above is well known to just about every student before middle school begins, so we also take it over at first. Gradually, however, we replace it with a local-action formulation which states, "Like poles are pushed away from each other by their magnetic field and unlike poles are drawn toward each other".

The same holds for electric interaction.

3. Two types of magnetic poles

Magnetic charge is a quantity which can take both positive and negative values. This is usually expressed by saying that there are two types of magnetic poles: North poles and south poles. This way of saying things leads to confusion. It suggests that magnetic charge has two qualities which are as different as "masculine" and "feminine."

Even when poles having the same sign are called "like" poles and poles with opposite signs are called "unlike" poles, the perception that there are two types of magnetic charge is being encouraged. In mathematics, for instance, the following would not be said: "The product of two like numbers is positive and the product of two unlike numbers is negative."

4. Graphic representation of fields

Field lines are used to graphically show a field, i.e. an invisible entity. This kind of representation has the advantage of summarizing a large amount of quantitative information about the field. It has the disadvantage, though, of giving the impression that the field is an entity which is connected in only one direction, the direction of the field lines. A static field can also be represented by equipotential surfaces lying perpendicularly to the field lines. This would give the impression that the field is connected only transversely to the directions of field strength. In order to avoid this impression, we will begin with other representations such as gray tones, points, and arrows.

By the way, at the middle school level, there is actually no convincing reason for preferring field lines over arrows because the quantitative information contained in field lines is not gone into at this level. The field lines do express what physicists mean when they say the field is solenoidal (divergence-free), but this cannot be formulated at the secondary school level.

5. Magnetic field strength or flux density?

Although magnetic fields are not discussed quantitatively at the middle school level, meaning they are not described by the vector quantities $\vec{H}$ or $\vec{B}$, the teacher must always be clear which of these he is thinking about when discussing a field. The qualitative statements that he makes about the field will depend upon which one it is.

Each of the quantities $\vec{H}$ and $\vec{B}$ has some advantages (Herrmann 1991).

Using $\vec{H}$ allows for a noticeably simplified treatment of magnetostatics because its structure is then fully analogous to that of electrostatics.

Just as it can be said in electrostatics that the $\vec{E}$ field lines begin at positive charges and end at negative ones, the $\vec{H}$ field lines of magnetostatics can be said to begin at north pole charges and to end at south pole charges. In addition, just as metal is $\vec{E}$ field free in its interior, soft magnetic material is $\vec{H}$ field free inside of it (but not $\vec{B}$ field free).

The statements in magnetostatics about the flux density $\vec{B}$ are more complicated. It is especially difficult with $\vec{B}$ field lines to make out where the poles of a magnet are.

This would be a good point to bring up the coloring of permanent bar magnets. Usually, one half of the magnet is colored red and the other half green. This suggests that the red half is one pole and the green half is the other pole, or even that the surface of the red part is one pole and the surface of the green part is the other. In fact, the poles are only found on the end faces of the magnet. Only these should actually be colored.

This false marking is based upon a misunderstanding. The poles of a magnet are not where the $\vec{H}$ or $\vec{B}$ field lines enter it (outside the magnet, these two quantities can still be identified with each other), but where the magnetization $\vec{M}$ and therefore, the magnetic field strength $\vec{H}$ have their divergence.

While magnetostatics is simpler when the magnetic field is described with the field strength $\vec{H}$, induction is more easily described by using $\vec{B}$. The value of an induced voltage can depend upon the time rate of change of the flux of the $\vec{B}$ vector field. $\vec{B}$ is the sum of field strengths and magnetization (up to a constant factor) so,

$$\vec{B} = \mu_0 \vec{H} + \vec{M}.$$

An induced voltage can (if $\vec{B}$ is not used) have two causes. First, a change over time of the field strength $\vec{H}$ and second, a change over time of the magnetization $\vec{M}$. At the high school level, it is worth working with $\vec{H}$ in magnetostatics and $\vec{B}$ in induction. At the middle school level, however, this is really not an option because the relation between $\vec{H}$ and $\vec{B}$ cannot be formulated and a choice between $\vec{H}$ and $\vec{B}$ must be made.

We have decided for the advantages of magnetostatics, meaning for $\vec{H}$. Induction is then only slightly more complicated.

6. Magnetization

The magnetization $\vec{M}$ is a vector field that describes the state of magnetization of matter. The sources and sinks of this field are what are called the magnetic poles. This means that the divergence of $\vec{M}$ can be interpreted as the "magnetic charge density" ρ_m:

$$\rho_m = -\operatorname{div} \vec{M}$$

If the magnetization of a body is known, then the location of the poles is also known. However, just knowing where the poles are does not uniquely indicate how the magnetization lines run.

The simple relation between the magnetization and pole locations is easy to discuss in class. It is clear that the entire body is changed by magnetization and not only the locations of the poles. It will be obvious that new poles form when a magnet is broken. It is also important to deal with magnetization because field strength and magnetization together form what students will later encounter as flux density.

7. Two induction experiments

There are two cases which are sometimes distinguished when dealing with induction. In the first, a permanent magnet is moved into a resting solenoid. In the second, a solenoid is moved over a resting permanent magnet.

Of course, both cases are actually the same experiment. It is just described in different reference frames.

According to our experience, no student in middle school considers this to be two different experiments. In fact, difficulties of logic could emerge if one attempted to describe the problem with the help of field strengths, meaning mathematically. At that point, the experiments begin to appear different because in one, a derivative with respect to time of the magnetic field strength appears, and in the other, it does not. It must then be demonstrated that the field strengths transform in such a way upon a change of the reference system, that the observable effects remain the same. As long as no mathematical description of induction is intended, differentiating between the two experiments simply appears unnatural.

8. Literature

HERRMANN, F.: Energy density and stress: A new approach to teaching electromagnetism. Am. J. Phys. 57, 707 (1989).

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MAXWELL, J. C.: A Treatise on Electricity & Magnetism. Dover Publications, Inc. New York (1954), p. 47.

HERRMANN, F.: Teaching the magnetostatic field: Problems to avoid. Am. J. Phys. 59, 447 (1991).

19. Electrostatics

1. The electric field after the magnetic field

There are both reasons for and against having electrostatics at the end of the subject of electricity. The reason we have put electrostatics at the end is because we wish to introduce the concept of fields within the subject of magnetism and not electricity. The student's first encounter with fields should not be a paltry entity such as an electric field, a field whose effects are only seen after a long series of precautionary measures have been taken.

2. Charge and charge carriers

We emphasize the difference between the *physical quantity* "electric charge" and the *physical system* "charge carrier." If this is not done, it is all too easy to consider electric charge and electrons as one and the same. Electrons, ions and other particles are not only carriers of electric charge. They also carry other (substance-like) physical quantities such as mass, amount of substance, angular momentum, momentum, entropy, etc. So a free electron can "carry"

electric charge	$Q = e = -1{,}602 \cdot 10^{-19}$ C,
mass	$m = m_e = 9{,}11 \cdot 10^{-31}$ kg,
angular momentum	$L = h/4\pi = 0{,}527 \cdot 10^{-34}$ Js,
amount of substance	$n = 1/N_A = 1{,}66 \cdot 10^{-24}$ mol.

The values of momentum and entropy depend upon the state of the electron.

3. The curious apparatuses of electrostatics

The apparatuses used in electrostatics experiments are totally different from the ones used until then in class. Among these are conductor spheres, Van de Graaff generators, electrometers and glow lamps. Section 19.3 describes why standard electric devices and measuring instruments cannot be used here.

20. Data systems technology

1. What the amplifier amplifies

Amplifiers are introduced here as devices in which the energy current accompanying a data current is increased. We believe it is better to begin this way than with treating an electronic amplifier circuit. It can happen all too easily that the students do not understand what an amplifier actually does. If the amplifier appears to be just a device for increasing electric currents or electric voltage, the question arises of why a transformer is not used instead. A transformer can also increase an electric current but at the cost of the voltage and vice versa. At best, the energy current remains the same.

2. Data reduction in the computer

Tests in class have shown that students do not find it difficult to understand that computers reduce data. However, some problems did arise when experienced mathematicians or physicists were approached with this. This may be because, in these cases, there is a certain way of viewing the quantity called amount of data (or “decision entropy”) which makes understanding more difficult. It seems to suggest that since the user becomes cleverer by using a computer, the computer creates data. In order to convince oneself in each individual case that this is not so (except in the case of the RANDOM instruction), the full Shannon formula must be applied to the problem. This means providing clarity about the probability distribution of the symbols at the entrance and exit of a computer. The whole thing becomes easier when the data provided by the computer is not considered to be used by a knowledge-hungry person, but is transmitted to control a machine.

3. Coding theory in physics class?

It would be possible to continue with problems of coding theory in class. Determining redundancy of language and images, devising the most redundancy poor codes possible, and much more. These are interesting and practical problems that are suited to instruction at middle school level. Nevertheless, we believe that these subjects should not be gone into in physics class because they are more suited to mathematics. This is a possibility for interesting discussions about information technology in the teaching of mathematics.

21. Light

1. The scope of the teaching of optics at the middle school level

The most important goal of geometric optics is to explain the optical image and its application in optical instruments. It is therefore clearly a part of applied physics. The applications being dealt with here are rather special, though. For this reason, the time we give geometric optics in the curriculum has to be compared to the amount of time given to other just as important applications of physics. We should consider it as competing with electronics, communications technology, hydrodynamics, energy technology and other technological disciplines. In our opinion, optics does too well here.

One should also compare it to other more fundamental aspects of physics such as thermodynamics. Indeed, the number of pages dedicated to optics in a middle school text book is often more than is given thermodynamics.

2. The subjects of geometric optics

There are many interesting subjects that could be discussed using geometric optics that are not normally included in school. Instead, optics is limited to a few very special and atypical phenomena. The impression might easily arise that light beams and light distributions only have meaning where someone is making an optical image when this is actually an exceptional circumstance.

Subjects associated with geometric optics that are as interesting as the usual subjects are:

– investigating light distributions as a function of position and direction under the most varied circumstances (fog or sunshine, for example);

– investigating non-imaging optical systems (non-imaging light concentrators generally have much higher concentration factors than image producing ones);

– describing light mixtures of varying coherence.

3. Light as a substance

We speak about light as we would about a substance. Indeed, a beam of light has much in common with a beam of material particles. Light has energy, momentum, angular momentum (spin), entropy, etc. just as a beam of matter does. Just like matter, light can be thought to consist of particles, the photons. Light can also be enclosed in a container, in the same way as a material gas. This is called cavity radiation.

In class we do not say that light propagates, but that it moves.

4. Local light distribution

When the light at a specified location is observed, statements can be made

– about the distribution of the directions of the light at this location;

– about the distribution of the wavelengths at this location.

The first statement refers to what is called spatial coherence. The second one refers to temporal coherence. A statement about the coherence of light is a statement about the light at just one location. Some textbooks give the impression that coherence is a property that refers to an extended field of light.

In fact, the coherence within a field generally changes from location to location. For instance, the spatial coherence of the light of an incandescent lamp increases the further away from the lamp it is.

It might be argued that one can surely not discuss the coherence of light at a certain *point*, and this would be correct. Points are mathematical abstractions that constantly lead to difficulties in physics. We can correctly say that pressure, temperature, and density are all local (meaning that they are quantities assigned to locations). However, in spite of this, it is impossible to give the values of these quantities for a point in the mathematical sense.

We have used the expression "spherical space R" in our text to represent a location.

The following is a comparison that can be used to give students clarity about the concept of coherence.

We have a crate with a lot of apples in front of us. The apples differ from each other in color and size. We wish to sort them into ten boxes according to size. Each box contains a different size interval. Now the apples are uniformly sorted according to one of the two criteria. Next we sort the apples in each box by color. We do this using ten boxes. In the end we have 100 boxes and in each box are apples which are uniform according to both criteria of.

The analogy of light and apples works surprisingly well. For example, one sees that well ordered groups of apples can only be made by separating out all the apples that don't match the criteria. It is just as impossible to transform mixed collections of apples into a pure uniform sort as it is to transform incoherent light into coherent light.

However, it is possible to grow trees that produce only one type of apple in the first place. The equivalent holds for light. A light source can be used which produces only coherent light. This would be a laser.

5. Radiance

In section 21.4, we make a qualitative investigation of the light distribution at a given location as a function of angle and wavelength. The physical quantity discussed in this case is the so-called spectral *radiance* which is the energy current density per solid angle and per wavelength interval. This is a quantity especially suited to describing radiation fields. It is best imagined as a field in a six-dimensional space: as a function of three position coordinates, two angles and the wavelength. It is even more consistent to give its distribution in phase space with three position and three momentum coordinates.

22. Optical image formation

1. Missing subjects

In our cautious attempt to streamline geometric optics, we have removed some topics and concepts from our treatment of it.

We have left out the expressions *real* and *virtual image*, *collecting lens, dispersing lens*, *convex lens*, and *concave lens.*

We have also avoided image construction with the help of parallel, focus and central rays. We believe that the effort involved is too great relative to the importance of the subject. Moreover, we have found that people (many physics students at their examinations) may have mastered the method in principle, but tend to fail at applying it to the most simple practical problems.

2. Optical systems with two lenses

It is not easy to understand why it might be practical to use more than one lens for an optical image. After all, it is possible to produce images of any magnification using just one lens.

Even if a student can correctly reproduce the optical path of a microscope or telescope, he will most likely not understand why two lenses were necessary for this.

We would have dispensed with microscopes and telescopes altogether if they had not already been planned into some curricula.

23. Color

1. Unknown color space

Three dimensional color space is an astounding phenomenon. It is very easy to convince oneself that every impression of color can be characterized by specifying three criteria. However, most people do not realize that color perceptions form a three dimensional space. This can be seen by how complicatedly color impressions are commonly described. It is widely believed that discussions about color have to do with subjective statements and that statements about color have only a limited scope of validity—considering that they are subject to various optical illusions. It appears that exact statements about color perception cannot be made at all.

In fact, optical illusions do exist and teaching color perception does has aspects that are very complicated. However, this subject also has another aspect that is free of any subjectivity. The fact that two color impressions considered one and the same by one person, are also found to be the same by every other (not color blind) person, is such an example. Grassmann's laws (Lang 1978) which imply that color impressions form a three-dimensional space, are a part of this.

The theory of three-dimensional color space has become especially important in the era of color photography and color television. It has also become convenient to experiment with color space now that we have computers because a great many colors can be produced on their screens.

2. The Topology of color scales

The subject of color space is also interesting for another reason. One of its three coordinate axes, the color tone axis, is closed. Within physics, there are only a very few scales with this characteristic. A somewhat trivial example of this is the scale of angles. Another rather complex example would be the spatial dimensions of a closed universe.

3. Names for colors

Three dimensional color space is generally so unknown that colors are very often given special names. These names sometimes come from the recipe used to make a pigment such as cadmium yellow, chromium oxide green, or sepia brown. Sometimes colors are named for objects having that color such as olive green, gentian blue, wine red, anthracite or egg plant. New, fashionable colors often have new names invented for them.

Students find it surprising that "undefinable" color impressions can easily be defined by specifying three parameters.

4. Additive and subtractive mixing of color

We do not use the words "additive" and "subtractive" for mixing of colors because we believe that these words do not contribute to clarity. Instead, they suggest that the processes described by them are related to each other. So-called additive color mixing actually has to do with combining light of two or more components. It would be better to call this process mixing of light. There are clear rules for the relation between the color impressions of the individual components and the light resulting from them. In so-called subtractive color mixing, nothing is actually mixed. Filters are just put one behind the other. There is no non-ambiguous relation between the color impression of light passing through one single filter and light passing through several filters placed one behind the other. A blue filter placed behind a yellow filter with sunlight passing through them could result in green, black, or some other color depending upon the absorption spectrum of the individual filters.

If one speaks about (additive or subtractive) mixing of colors, the impression of mixing pigments is easily given. In fact, in creating the color tone of a pigment mixture, both the mixture of light as well as the filter effect of the pigments plays a role.

5. The metric of color space

Our representation of color space is qualitative, i.e., we do not give its metric. This would not only be complicated, but also unnecessary because the most important statements can be gained without metric. The 12 color tones we have chosen and named should actually be more exactly determined by colorimetric considerations. Instead, the color scale we use in class has been determined simply by showing the appropriate colors. (Using the filters which come with a color projector, six of these colors become available).

We give only 12 colors on the circle names for the following reasons. The number should always be divisible by three so that the three basic colors of a television screen each have their own name. With six colors, we should have exactly one name for each television color and one for each of their complementary colors. These colors are yellow-green, blue, red, turquoise, purple, and orange (these are the colors of the filters in the demonstration collection). The disadvantage here is that the important colors yellow and green are not among the color tones named. For this reason, we have doubled the number of color tone names.

6. Literature

LANG, H.: Farbmetrik und Farbsehen, Oldenbourg Verlag, München (1978).

24. Rate of reaction and chemical potential

1. The analogies to mechanics, electricity, and thermodynamics

We deal with physical chemistry from the same viewpoint we deal with mechanics, electricity and thermodynamics: By describing processes in terms of currents. When a current is dissipative, we say it is hampered by a resistance. The difference in the values of the corresponding intensive quantities acts as a natural drive for a current. This driving force is necessary for overcoming the resistance.

In chemistry, conversion rate takes the role of current. Chemical tension (the difference between the chemical potentials) acts as the driving force for a chemical reaction.

Of course it would also be possible to include actual currents of amount of substance. Diffusion processes could then be treated: A chemical potential difference would appear as the cause of a diffusive current of amount of substance.

There are reaction resistances in chemistry just as there are mechanical, electrical and thermal resistances.

2. The chemical potential as a physical quantity

It seems natural to introduce the chemical potential as a physical quantity. Indeed it does lurk in chemistry textbooks—but without calling it by name and without assigning it any values.

Metals are categorized according to their tendency to bind with oxygen and are labeled precious to one extent or another. Redox couples are organized into redox series. The ability of an atom to react with electrons is described by "electronegativity." All of these cases actually deal with the same concept: The qualitative or quantitative statement about chemical potential differences (Job 1981). All of these characteristics or values can be read in just one table, the table of chemical potentials.

3. Questions in chemistry

The goal of this teaching unit is to answer some simple and important questions which can arise in relation to some reaction a chemist may be working on:

What direction does the reaction run in?

How fast does the reaction run and can it be accelerated or inhibited?

How much energy is obtained in the reaction process?

How much entropy ("heat") is absorbed or emitted during the process?

Actually, there is one more question which belongs to this group: How can the direction the process runs in be influenced? It is equivalent to the question: How can the location of a chemical equilibrium be shifted? We refrain from answering this question in our curriculum because in order to answer this, it would be necessary to deal with the pressure and temperature dependency of the chemical potential. Although this is a simple enough subject (Job 1978), it is too extensive to be included here within the framework of physical chemistry.

4. Values of the chemical potential

How are the values of chemical potentials obtained?

The answer to this question is very similar to the answer to the more general question of how the values of any arbitrary physical quantity are obtained. It is the question of a measuring procedure. However, we must always clearly distinguish between the specification of a measuring method based upon the definition of the quantity (this is equivalent to an operational definition of the quantity), and the specification of a practical, technical measuring method.

Temperature is defined by the relation

$P = T I_S$

A method resulting from this definition is to measure the entropy current I_S and the corresponding energy current P and then dividing P by I_S.

However, practical methods of measuring temperature function very differently. We typically measure the elongation of a liquid column, an electric resistance, or a thermoelectric voltage. The scales of the corresponding measurement devices must, of course, be calibrated with the help of the defining equation of temperature.

Measuring chemical potential differences is very similar. In principle, they can be measured by using the defining equation

$P = (\mu(\mathrm{A}) - \mu(\mathrm{B})) \cdot I_{n(\mathrm{R})}$

In reality however, they are measured differently. There are many different practical measurement methods (Job 1981). This is because there are a large number of different reactions involved.

At the middle school level, we will limit ourselves to a discussion of the defining equation and we will take the values of μ from Tables. (The same will be done for the values of amounts of substance. We will determine them by the molar mass m/n which we will take from the periodic table.)

This method is not much different from what is done with other physical quantities. We often determine the value of physical quantities with measurement devices whose mode of operation we do not ask about in class. We do so when measuring the temperature with a digital thermometer, a mass with a magnetic analytic balance, or a time intervals with a quartz clock.

It is important that students develop a trust of these devices. This can be done by carrying out measurements in situations where the students have a good idea of what the result will be. Their expectations should be confirmed by the measurement.

Similarly, trust in the table of chemical potentials can be generated by using its values to determine the directions of reactions students already know.

5. The zero point of the chemical potential

Chemical potential is a quantity which has an absolute zero point, just as temperature does. As long as only chemical reactions (meaning no nuclear or elementary particle reactions) are being observed, it is permitted and even advantageous to choose as many zero points as there are chemical elements.

In order to describe reactions in which ions participate, an electrically charged particle must be included along with the chemical elements. It is usual to set the potential of the hydrogen ion H^+ in a aqueous solution to 0 Gibbs.

6. Amount of substance as a basic quantity

The quantity called amount of substance n is a basic quantity for chemists. Nevertheless, in the traditional teaching of physics and chemistry it is only introduced in a half-hearted way. It is used as a measure of an amount of a substance but never appears in any physical equation.

In our course, it plays an important role, though, so it is necessary to introduce it with great care.

7. Literature

JOB, G.: Das chemische Potenzial im Physik- und Chemie-Elementarunterricht. Konzepte eines zeitgemäßen Physikunterrichts, Heft 2, S. 67. Hermann Schroedel Verlag KG, Hannover 1978.

JOB, G.: Die Werte des chemischen Potenzials. Konzepte eines zeitgemäßen Physikunterrichts, Heft 4, S. 95. Hermann Schroedel Verlag KG, Hannover 1981.

JOB, G. and HERRMANN, F.: Chemical potential – a quantity in search of recognition, Eur. J. Phys. 27 (2006), p. 353-373.

25. Amount of substance and energy

1. Electrochemical cells

Electrochemical cells are known by a number of names. Some of these names refer to function, like fuel cell. Others refer to their inventor, such as the Leclanché element. Some refer to the structure of the cell (e.g., alkali cell), while still another name, accumulator, refers to the fact that a cell can be driven in two directions.

We have tried to put some order into this diversity by using the superordinate term “electrochemical cells.” If cells absorb electric energy (energy with the carrier electricity) we call them “reaction pumps” and when they emit electric energy, we call them “electricity pumps.”

The confusion of names will not be increased by this because these new names just serve to make understanding the functions of the cells easier. They are names we are only using here in this course.

Of course, these names also help in recognizing connections. We used the term electricity pump earlier in the subject of electricity for describing all devices which emit energy with the carrier electricity. Correspondingly, in thermodynamics we introduced entropy pumps, the technical name of which are heat pumps. In mechanics, we saw that motors work as momentum pumps.

2. Irreversibility of electrochemical cells

In our description of electrochemical cells we refrain from dealing with the creation of entropy and pretend that the cells work reversibly. We do this for the same reasons we refrain from dealing with the creation of entropy in a solenoid, in an electric motor or in a pulley: entropy production is not essential to the functioning of these devices and describing their function is easier when entropy production is left out.

Entropy production is primarily based upon the process of charge transport in the electrolyte. This can be reduced to any desired extent by having the cell run almost at open circuit conditions. The resistance of the outer part of the electric circuit needs to be high compared to the internal resistance of the cell.

26. Heat balance of reactions

1. The balance of entropy in reversible reactions

Discussing the balance of entropy of a reaction would be much easier if it were possible to use reversible electrochemical reactions. One would, however, also need electrochemical reactions where the temperature decreases.

Such reactions do exist, but they must be allowed to run very slowly. They lead to an immeasurably small temperature decrease. If these reactions are allowed to run at a reasonably high conversion rate, temperature does not decrease but increases due to the greater amount of entropy being produced.

2. Exothermal and endothermal reactions

Categorizing chemical reactions into exothermal and endothermal is done using a very striking criterion: whether or not the reaction products are warmer than the starting substances. However, as every chemist knows, this is a very superficial criterium.

It does not tell us whether energy can be obtained from a reaction or in which direction the reaction voluntarily runs. The reason is that the heat effect of a reaction has two very different causes. One is the dependency upon the specific heats of the reactants and products, the other is the dependency upon the chemical tension of the reaction.

Except in the case of normal phase changes, endothermal reactions are rare and could simply be left out of instruction. If, however, they are discussed, the two contributions to the heat effect should be clearly separated.

3. Phase changes

Phase changes would lend themselves well to being treated as chemical reactions and to being described with the concept of "chemical potential." This would be interesting because endothermal reactions are very common here. Evaporation cold (latent heat of evaporation) is a well known example.

We have decided for two reasons to refrain from covering phase changes in this way.

First, it would be necessary to deal with the temperature dependency of the chemical potential beforehand, and this is not done here.

Second, the phase changes best known to everyone are bad examples for describing chemical tension as the drive of a reaction. The most common phase changes (solid to liquid, liquid to gas) as well as their reversals, run almost totally uninhibited. The reaction resistance is so low that a chemical tension never develops and the two phases always remain in chemical equilibrium. In order to make clear that there is a drive and a resistance at work here, the somewhat exotic phenomena of delayed boiling and supercooling need to be discussed.

27. Relativity

1. Relativistic kinematics and relativistic dynamics

The most important objective of this chapter is to show that mass and energy are the same quantity. This is one of the most important statements in relativistic dynamics.

The reason the theory of relativity holds such fascination for so many is, however, something totally different. The fascination lies in the phenomena of relativistic kinematics such as length contraction, time dilation, twin paradox, and so on. They are not covered here for the following two reasons.

First, relativistic kinematics is too involved – so involved that even experienced physicists have problems with it. It is simply too difficult for middle school.

Second, it is also unproductive. There are only few phenomena of relativistic kinematics important enough to justify covering the subject.

The phenomena of relativistic dynamics that appear here are, by contrast, simple. They do have important consequences, though, which are brought up in later chapters.

2. Exergy

Some authors discuss the subject in Section 27.3 using the concept of exergy. We are decidedly against introducing this quantity.

Unlike energy, the quantity exergy cannot be localized. It is impossible to say what system it is stored in.

Moreover, its value is dependent upon the environment of the system in question. The environment being considered is always the result of an arbitrary decision (Herrmann 1987).

3. Literature

HERRMANN, F: “Plädoyer für die Abschaffung der Exergie”, DPG-Tagungsband, Fachausschuss Didaktik der Physik, 1987.

28. Waves

1. Waves as periodic processes

Waves are often introduced as temporal and spatial periodical processes. It is also often emphasized that a wave can be considered a collection of many coupled oscillators. The wave machine made up of many coupled pendulums which is found in school labs, strongly suggests this. We believe that this way of introducing a wave emphasizes a less important characteristic of waves too strongly and leaves an important one unclarified.

Indeed, periodicity is only characteristic of a special type of wave. Many important waves appearing in nature have absolutely no periodicity. The coherence length of sunlight and the light of a light bulb is, for instance, no greater than the average wave length. There is not much periodicity to be seen in this case. Most of the sound waves coming into our ears are not periodic. Physicists tend to see periodicity everywhere because of their habit of immediately making a Fourier analysis of waves. One should remember, though, that there are numerous other ways of breaking a wave down into components.

We consider the fact that a wave is an independent physical system more important than the periodicity of some waves. The transport of very different physical quantities is connected to the "propagation" of a wave. These quantities are energy, momentum, angular momentum and entropy. Of these quantities, we will only discuss energy at the middle school level. We refer to the wave as we would to a body by saying, for instance, that the wave "moves" instead of "propagates."

2. Wave carriers

In order to emphasize that a (mechanical) wave is an independent entity, we make a point of differentiating between the movement of the wave and that of the carrier of the wave. The speed at which the air moves in a sound wave is usually called sound particle velocity. We prefer to call it the *velocity of the carrier* of the sound wave.

Stressing the role of the carrier of a wave in the case of mechanical waves, leads to the question of what the carrier of an electromagnetic wave is. This question is usually avoided at both the school and university levels in order to avoid a discussion of ether. Here, we consciously address this problem and give, as well as possible at the middle school level, the answer of modern physics: Electromagnetic waves are excited states of the "vacuum."

The word vacuum (emptiness) is actually inapt in this case. It only hits the mark if this state means the absence of excitation. A word describing not the absence, but the presence, of something would be more suggestive. In the past, things were easier. The carrier of a wave was called "ether" (Mie 1942) until quite far into the 20th century. Unfortunately, this word has a stigma that it has never been able to overcome: Until around 1900, electromagnetic waves were considered mechanical waves of the ether. Instead of newly describing ether using the characteristics stipulated for it by relativity theory, the word was simply eliminated from physics. Instead, the word vacuum has been used to describe something it is not well suited for.

3. Electromagnetic waves at the middle school level

The subject of electromagnetic waves is generally considered too difficult for middle school. It actually is difficult to introduce these waves as it is proposed in university textbooks. Electromagnetic waves are important in both nature and technology, so it would be desirable to find a version that is appropriate for the teaching at the middle school level.

The simplicity of the method presented here for covering this subject is due to the following differences to the usual treatments of it at the high school and university levels (which typically follows Hertz' example).

- We limit our discussion of the generation of the wave to the magnetic fields.
- We choose a long wire as our antenna instead of a short dipole.
- We do not assume that the antenna itself is a resonator. It is also easier to describe the generation of sound by using a loudspeaker (without a natural oscillation) than with an organ pipe (with natural oscillation).

4. Interference experiments

We demonstrate interference of light with the most simple experiment possible: Fresnel's double mirror experiment. We do not show interference using the double slit experiment because there are two aspects which make it more complicated than Fresnel's experiment:

- It does not deal with plane waves, but with spherical waves. The location of extinction is not a group of planes as with Fresnel's double mirror experiment, but a group of hyperboloids.
- The spherical waves are produced by diffraction, a subject not covered at middle school.

It is obvious that instead of a double mirror, a much simpler experimental apparatus could be chosen (and this is sometimes suggested by students): Using two lasers whose beams cross at an acute angle.

Of course, the experiment is unsuccessful because the oscillations of the two lasers are independent of each other so they repeatedly get out of step. The average amount of time that they are synchronized with each other is only

Coherence length/Speed of light,

which is of the order of 1 ns. Each time the lasers get out of step, the interference image shifts. Naturally, the eye cannot follow such fast motion.

If a student suggests this method, assure him that it is a good idea but cannot be realized for technical reasons: Lasers are not good enough.

This experiment would actually work using two parabolic radio antennas which are supplied by the same radio frequency power unit.

5. Literature

MIE, G.: Lehrbuch der Elektrizität und des Magnetismus. Ferdinand Enke Verlag, Stuttgart, 1948. S. 55.

29. Photons

1. Light as a substance

There is a widespread idea about light and its elementary particles (photons) which is not only misleading, but actually wrong. It states that light is a form of energy, that electromagnetic radiation is pure energy, and that photons are quanta of energy. Such statements only show that the one making them has mistaken energy for a *physical system*, namely an electromagnetic field. A physical system is always described by a group of physical quantities and the relations between them. To say that light or electromagnetic radiation is pure energy is just as incorrect as saying that an ideal gas or electrons are pure energy. Along with energy, light has momentum, angular momentum, entropy, amount of substance, pressure, temperature and chemical potential, just as any ideal gas or any other system has.

It is important to make it clear in class that light has great similarity to a substance. It might even be said to be a substance. The elementary portions of the "light substance" are photons. They correspond to helium atoms, the elementary portions of helium, and water molecules, the elementary portions of water. To make this clear from the start, we begin with a section on photochemical reactions. It becomes clear here that light is a reaction partner to be taken as seriously as any other "material" substance.

The fact that the symbol γ does not appear on both sides of the reaction equation (as it does for chemical elements), should not bother us. The reason is that in reactions, light is either created or destroyed. Students will have to get used to the fact that the number of atoms appearing on the left and right sides of a reaction equation for nuclear reactions will not be the same.

It is also important *not* to represent light in a reaction equation using the symbol *hv* which is not the name of a substance, but an energy value. Avoiding this symbol also helps to avoid the misunderstanding that light is pure energy.

2. The size of photons

How is the size of an object defined? The answer would appear to be simple: The distance between the beginning of it and the end of it. The question can also be asked more generally: What is the shape of an object? The answer is: The shape of its border or surface. In the following, when we refer to the size or shape of an object, this is what we will have in mind.

Now, what shape does a photon have? In order to answer this, we need to know where it begins and where it ends or, respectively, where its surface is. It might be said that the beginning and the end of a photon cannot be determined, and certainly not its surface. This would mean that a photon has no size. The concept of size in the sense of extension comes from our experience of the macroscopic world. This concept cannot be applied to microphysics or quantum physics. Therefore, the question of the size of photons makes about as much sense as asking what color an atomic nucleus has.

If we subscribe to this view, we must also strike several questions and answers from our repertoire. A model is always used in the discussion of photons. For example, it is said that photons are emitted from a light source and then absorbed by some other body. The model here is of an individual entity which can be followed as it moves through space. We do not necessarily wish to abandon this model but if it is used, the assumption is made that a photon has a certain size and it is very small.

The statement that a photon moves from a light source to an absorber only makes sense if the photon is smaller than the distance between source and absorber. If the source is 10 cm from the absorber, it follows that the photon is shorter than 10 cm. However, source and absorber can be as close as 1 mm or 1 *μ*m apart. In this case, it is assumed without expressly saying it, that the photon is shorter than 1 *μ*m.

Some textbooks even state that elementary particles are point-like. This does not make much sense because even if a measurement of an electron were to show that its diameter is 10^{-30} m, this is not a point. The concept of a point is a metaphysical concept, a creation of the human mind. Whether a particle is point-like cannot actually be verified or disproved.

Our conclusion is that although no one admits it, the theory that photons are very small continues to be circulated. In any case, students at all levels are led to believe it because if the model of an individual moving entity is used, the question of shape and size is legitimate. In addition, if we do not answer these questions, students will answer them for themselves. We then give up control of the learning process at a very crucial moment.

If we allow photons to fly around, we must also tell students about their size and shape.

What is their size then? Or better: Does the model allow for assigning a photon a size?

This question is easy for physicists to answer. If it embarrasses us to give the beginning and end or the border of a photon in the macroscopic sense, there is another good answer. Which of the characteristic quantities of photons with a dimension of length does the theory of photons present us with? There are two candidates: wavelength and coherence length.

We can eliminate wavelength right away because the photon in our model is an entity in three-dimensional space, and wavelength is a one-dimensional quantity.

On the other hand, coherence length is a very good measure of the size of a photon, or more exactly: the three dimensional coherence area. This has a clear shape which can be measured. We interpret the coherence area of a particle as the area of space taken up by the particle. The shape of the coherence area is the shape of the particle. Later on, we will apply this to electrons.

This interpretation of particle size is no caprice of the KPC, it is well known to experts in this field, even if it is seldom expressed as explicitly as we are doing it here (Greenberger 1983).

Another way of stating this is that the shape of a particle (a photon or an electron) is given by the uncertainty relation. The spatial uncertainty is interpreted as the area taken up by the particle.

A particle's spatial uncertainty is a measure of the particle's size.

A consequence of this:

The size of a photon (or electron) depends upon its state.

Here are a few examples of the shape of photons in this sense. The photons of sunlight here on Earth for a cloudless sky are about 1 *μ*m long with an extension of about 40 *μ*m transverse to the direction of movement. The photons coming from a laser are, by contrast, long and thin. They are as wide as the laser beam (about 1 mm) and as long as the coherence length, (10 cm, for example). A radio transmitter's electromagnetic waves have photons that are even much larger. They cover the entire transmission area.

3. Wave-particle duality

In the traditional interpretation of quantum mechanics, a "microobject" sometimes appears as a wave and sometimes as a particle. This problem does not arise in our physics course. In the following, we use electrons for our description of micro-particles because it is the most familiar one to physicists. Statements made about them are also valid for photons and other particles.

According to quantum mechanics, the wave-like character of an electron is most pronounced when it is in a state of sharp momentum (with a well-defined wave number). The location is then very unsharp. The particle character becomes clearest when the system is in a state of a sharp position and totally unsharp momentum.

Particle and wave are two concepts used in modeling. The perfect particle is point-like and has a location which can be defined by just one point in space. (This is totally different from macroscopic bodies whose locations cannot be determined by one point. They always occupy an entire area in space.)

By contrast, the perfect wave is sinusoidal and infinitely extended. Therefore, its momentum represents just one point in momentum space.

In an arbitrary state of an electron neither of these models apply. When the electron undergoes a process in which its state changes, so that it goes from a state of sharp momentum to a state of sharp position, a problem arises if one attempts to apply one of the extreme models, i.e., particle (point in position space) or wave (point in momentum space). One tries to avoid this conflict relying upon the crutch called "wave-particle-duality"

This problem does not occur if the unsuitable models "point-like particle" and "infinitely extended sine wave" are not used in the first place. Rather, we should describe the size of the particle by the spatial area which is taken up by the wave function.

We do not use the word "particle" to mean a point-like entity. We use it no matter what state the electron or photon is in.

4. Literature

GREENBERGER, Daniel M.: Reviews of Modern Physics 55, 898 (1983).

30. Atoms

1. The traditional model

According to the traditional model, an atom is composed of a heavy nucleus with electrons moving in its surroundings. These electrons do not move upon specific paths so that occasionally it is said that the concept of paths loses meaning. We consider this model to be inapt, at least for schools. It is totally acceptable for a model not to reflect reality. In fact, it is a very normal trait of models that they accurately describe only certain aspects of reality. What is required of a model is that it be self-consistent, it should not contain any contradictions in logic. However, this modest requirement is not fulfilled by the traditional model of an atom. One is expected to consider an electron to be a small moving body while also accepting that it follows no path. How, then, should the movement of this little body be visualized?

2. Electronium and electron

We use the same model for electrons that we do for photons by saying that electrons are expanded entities. Their shape is described by their wave function, so the shape depends upon their state. An electron is very small in a state of sharp position and very large in a state of sharp momentum. In order to describe such an electron, a name is needed for something that does not exist in the traditional model: a name for the substance the electron is made up of. We have chosen the name *electronium*.

Introducing this name makes describing atomic structure easier. An atom is made up of a small heavy nucleus and a large, light shell composed of electronium. This electronium becomes increasingly dense towards its center. Logically, it becomes increasingly less dense toward the outside and has no sharp edge. When one removes electronium from the atom, one finds that it can only be removed in certain portions: A certain amount of electronium (the mass is used as the measure) or multiples of this amount. We call this elementary amount an electron.

In the states that quantum mechanics calls the eigen-states of energy, the distribution and shape of the electronium remains constant in time.

This way of dealing with electrons is basically nothing new. Atomic physicists, chemists and crystallographers constantly work with this model. However, instead of using the word electronium, they speak of orbitals or electron density distributions. From the way they express themselves, it is easy to see that only the actual word is missing to describe the substance they are referring to.

3. Probability density and transition probability

The square of the single-electron wave function $\psi(\boldsymbol{r})$ is traditionally interpreted as the density of the probability of finding the particle at the position $\boldsymbol{r}$. How is this interpretation arrived at?

We will describe the procedure traditionally called position measurement by first using the language of theory, then in the words of the traditional model, and finally with the words of our electronium model.

In measuring the position of an electron (for example, the electron in a hydrogen atom), the electron goes from a state of sharp energy and unsharp position, such as the 1s-state of hydrogen, into a state of sharp position and unsharp energy. In this state, the square of the magnitude of the wave function is a delta function.

Now the interpretation according to the traditional model: If the position measurement of an electron in the 1s ground state is repeated several times, various position values are obtained having a distribution which can be described by $|\psi(\boldsymbol{r})|^2$. Because the assumption is made that the particles were point-like even before the measurement, the following interpretation of the measurement procedure must also be made. Before they are measured, the particles are swarming around the nucleus, following no particular orbital paths. They appear at certain positions with certain probabilities. The position measurement then tells us where a particle is located at the moment it is being observed. The particle reveals its position.

Finally, the electronium model interpretation: This process should not even be called position measurement, but the transition from a state in which the electron is large to a state where it is small. In the process of transition, it contracts down to a small area of space. If this process is repeated numerous times, one sees that the electron contracts at the most varying positions. The probability for the different positions where the small electron will be found after the transition is described by $|\psi(\boldsymbol{r})|^2$, meaning the density of the electronium before the transition. Thus, $|\psi(\boldsymbol{r})|^2$ can be interpreted as the density of a transition probability.

4. The shell model

The shell model is often used for describing the characteristics of atoms, especially the periodicity of atomic radii and ionizing energy with increasing atomic numbers. A many-electron atom can gradually be constructed by stepwise adding one proton to the nucleus (and one or two neutrons) and adding one electron to the shell at the same time. This gradually increases the atom, shell by shell—according to the shell model. Each new electron is imagined to be an individual entity which attaches to the outside of the atom. In this way, one shell after another is being filled. Each time a shell is filled, the ionization energy reaches a maximum. Atoms with completed shells are especially stable. The atomic radii for atoms with completed outer shells should have a minimum and atoms with just one electron in the outer shell, a maximum. These maxima can actually be observed, but the minima lie in the wrong location. In spite of this, the model can be considered a good one.

Some authors appear, however, to find the observable proof of this model unsatisfactory. Allegations are made which are unfounded and evidence is even faked only resulting in students being given a false perception of what an atom looks like. More exactly, they receive a false impression of electron density distribution, or electronium distribution, as we call it.

Obviously, one wishes to prove that the electron density in a many-electron atom oscillates outwards from its center, and that the shells of a completed atom can be observed. In other words, one gives the impression that the individual electrons in the atom can be observed, even if in only a limited way.

The electron density distribution of an atom from the nucleus outwards, is a strongly diminishing monotonous function, Fig. 30.1a, where there is almost no evidence of shells. However, shells can be generated by a mathematical trick. Instead of plotting the electron density ρ as a function of the radius, meaning the function $\rho(\vec{r})$, this function is integrated over the entire solid angle, and the result is represented as a function of r. Atoms are almost always spherically symmetrical, so the result is simply the product of $r^2\rho(\vec{r})$. This function actually does show some oscillations for atoms of higher atomic numbers, Fig. 30.1b, but this gives a misleading picture of the electron density distribution.

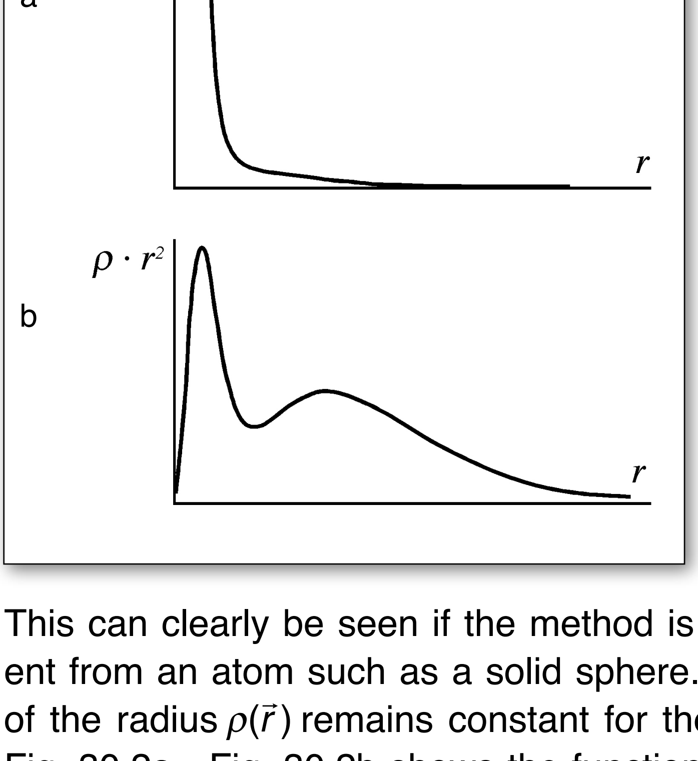

Fig. 30.1
(a) Density ρ of electronium as a function of the distance from the nucleus for a carbon atom.
(b) The quantity $\rho \cdot r^2$ as a function of the distance from the nucleus for a carbon atom.

This can clearly be seen if the method is applied to an entity different from an atom such as a solid sphere. The density as a function of the radius $\rho(\vec{r})$ remains constant for the sphere, as expressed in Fig. 30.2a. Fig. 30.2b shows the function $r^2\rho(\vec{r})$. The actual density distribution is difficult to make out in this representation. Instead, it expresses the trivial fact that a sphere has more mass toward the outside than toward the inside.

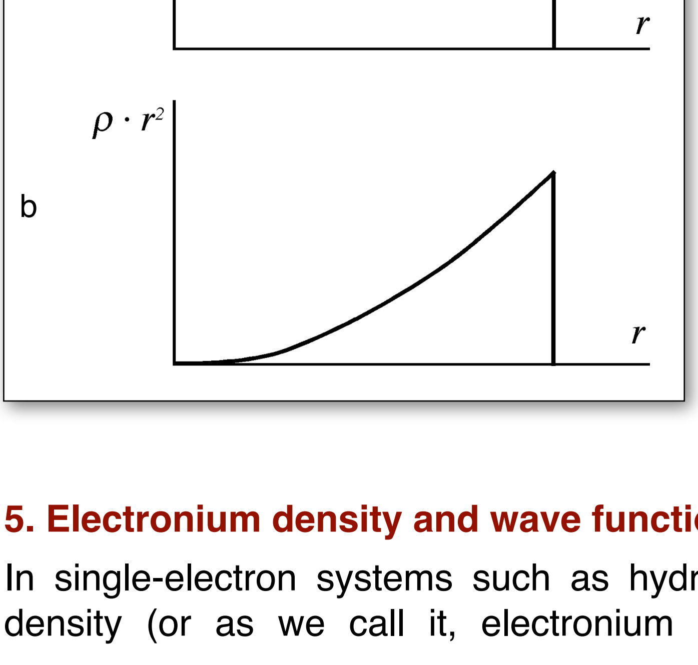

Fig. 30.2
(a) Mass density ρ as a function of the distance from the center of a homogenous sphere.
(b) The quantity $\rho \cdot r^2$ as a function of the distance from the center of a homogenous sphere.

5. Electronium density and wave function

In single-electron systems such as hydrogen atoms, the electron density (or as we call it, electronium density) $\rho(\vec{r})$ is simply the square of the wave function:

$$\rho(\vec{r}) = |\psi_{1s}(\vec{r})|^2$$

The electron density distribution contains essentially the same information as the wave function. (More exactly: the density and the current density together are equivalent to the wave function.) This is very different in many-electron systems. In this case, the wave functions depend on as many position variables as there are electrons. However, as before, the electronium density is a function of only one position variable. Therefore, the wave function contains much more information than the electronium density. Electronium density cannot tell us about many atomic characteristics such as which bonds an atom will form with other atoms.

6. The empty atom

The point-particle model of the electron leads to another discrepancy. It is often emphasized that most of the space taken up by an atom is empty. This statement may be edifying, but its meaning is doubtful. The wave function of the electrons does not tell us anything like this. Emptiness results only if electrons are interpreted as point-like entities. However, if electrons are point-like, then all other elementary particles such as quarks, must be as well. The entire space then must be empty. What should students make of such statements?

According to the electronium model, the space taken up by an atom is not empty by any means. A substance called electronium exists there. It has a well defined mass density and charge density.

7. Exponential decay

Exponential growth and exponential decay are certainly very important and universal phenomena. Radioactive decay is a prime example of applying exponential functions in physics. This is the only example that many students will encounter in physics class and leads to the curious impression that exponential functions only appear in nature in relation to radioactivity. In order to counteract this impression, we introduce exponential functions already for the decay of the excited state of atoms.

Another fundamental phenomenon of physics is that the course of a process may be determined by probabilities. This fact is usually only dealt with in relation to the fringe phenomenon of radioactivity. We go deeply into the subject of the decay process of excited atoms in order to emphasize the importance of probability statements.

8. Applications of atomic physics

One application of atomic physics that we will naturally deal with is spectral analysis. A phenomenon we consider more important because it appears so often in everyday life, is the radiation of gases. We will go into it in detail applying it to gas discharge lamps and glowing flames.

31. Solids

1. The electronium of solid substances

The electronium model can be effortlessly carried over to solid substances. Here, as well, it can be said that the ideas of standard physics about the microscopic structure of solid substances correspond to this model. The electronium density distributions of solid substances are measured by using X-ray diffraction and calculated by theorists.

Again, we contrast the traditional idea of point-like electrons with the electronium model. In doing so, we refrain from dealing with the thermal motion of atomic nuclei.

The traditional image of a solid body looks like this: Point-like electrons move between the atomic nuclei. The probability of finding an electron is highest at the nuclei. Since the electrons are actually point-like, the solid substance is essentially empty.

In the electronium model it is the electronium that fills the space between the atomic nuclei. It is densest near the nuclei. The density decreases when moving outward from the nuclei.

2. Energy bands and energy ladder

Just as with individual atoms, excitation of a solid substance has to do with changes to the density distribution of its electronium. In the case of atoms, only certain different forms can be assumed, while for solid substances there are entire ranges of forms that can continuously change into each other. Correspondingly, there are continuous ranges of excitation energies. Such ranges of allowable energies (and density distributions) alternate with forbidden energies (energies which the solid substance cannot absorb).

We describe a solid substance by its energy spectrum or *energy ladder*. Energy ladders allow us to make some important statements about solid substances just as they do with atoms.

Allowable energies on the energy ladder are those energies that can be stored by the solid substance. This means that we do not ask whether we are dealing with the excitation of a single electron or a collective of them. The concept of energy ladder is not dependent upon a model. An energy ladder gives the energies which can be determined experimentally.

An energy ladder is a simpler and more limited description of a solid substance than a band model is. In a band scheme, energy is represented as a function of position.

3. Optical properties of solids

It would be a good idea to give a complete description of the optical properties of matter in a chapter on solid-state physics. This would include everything that the eye perceives when looking at the surface of a solid body.

Two functions are necessary for fully describing the optical properties of matter: Real and imaginary parts of the complex refractive index. In our course, however, we have just one function available and that only in the rudimentary form of the energy ladder. Therefore, we cannot explain all optical properties. In particular, we cannot explain the phenomena of reflection and diffraction.

However, many other phenomena can be explained well and we have made use of this possibility. We can explain why metals absorb visible light, why most non-metals are transparent, why other non-metals such as cadmium sulfide are transparent as well as having color, why semiconductors allow infrared light through, why black substances are black and white ones are white.

4. Solid substances as light sources

Solid substances can emit light just as gases can when the electron system goes from a state of higher excitation to a state of lower excitation. As in the case of gases, excitation can occur in various ways:

1. by means of fast moving electrons (example: television screen);

2. with photons (example: the luminescent substance on the inner surface of a fluorescent tube);

3. in a chemical reaction (example: the reaction between electrons and holes in the p-n junction of a light emitting diode);

4. by heating (example: glowing).

Glowing bodies are some of our most important sources of light. The glowing filament of a light bulb, or the glowing carbon particles of a candle flame are among them.

Oddly enough, this subject is usually given small attention. High school graduates are expected to be able to explain how a laser works but the corresponding microscopic treatment of glowing is not covered in class.

5. Electric properties of solids

Electronium in metals can be “deformed” with an amount of energy, that can be arbitrarily small. Deforming means realizing a deviation from the density distribution of the ground state. Such a deviation is made up of a densification at certain locations and a rarefaction at others (as compared to the ground state). The densification as well as the rarefaction can be pushed through the solid by means of an electric field. This is how electronium and thus electric charge, are transported.

For people unaccustomed to dealing with electrons and holes, the question might arise of how our compression and rarefaction relate to the electrons and holes of the usual band model.

First, some general remarks about electrons and holes. These concepts are used for describing the transport of electric charge. We will consider a certain band which is responsible for such a transport. The transport can be described using either electrons or holes and the result will be the same. The effective mass of the electrons depends upon energy. It has a different value at the lower edge of the band than at the upper edge. In particular, the effective mass at the lower edge of the band is positive, and at the upper it is negative. Just the opposite holds for holes: Their masses are positive at the upper band edge and negative at the lower one.

The fact that the effective mass does not remain constant generally makes describing the transport process complicated. There are situations, though, where it is simple.

If a band is sparsely filled with electrons, their mass is positive and essentially constant and they behave like free electrons. The transport of electricity in such bands is best described with electrons.

A description with holes would give the same result, but the reasoning would be more complicated. For one thing, there are many more states for holes whose contributions to the transport would need to be taken into account. In addition, these holes have differing masses, some of which are even negative.

Correspondingly, charge transport in a band almost full of electrons is described more advantageously using holes. These are less numerous than electrons and have a uniform, positive effective mass.

These considerations show that it is not completely accurate to say that the Hall effect lets us know if we are dealing with an electron conductor or a hole conductor. Any transport can be arbitrarily described with either electrons or holes. Rather, the Hall effect tells us if a band is heavily or sparsely filled with electrons.

Back to the electronium model: It is not only possible to describe the transport of electric charge with either electrons or holes. A mix of the two is possible as well. This is what we do with our compressions and rarefactions. This description also yields the correct total current through the solid body. (Laukenmann 1996)

6. Semiconductor diodes

Semiconductor diodes are actually too difficult a subject for middle school. We therefore give more of a description than an explanation of a diode’s processes. A full explanation of the functionality of a diode is not possible by means of electricity alone. The current of the charge carriers in the diode is not only determined by the gradient of the electric potential, a chemical potential gradient is needed as well. In other words: The gradient of the electrochemical potential is responsible for the total current.

7. Transistors

We limit ourselves to field effect transistors. Usually, bipolar transistors are given preferential treatment because they were developed earlier and put into practical use long before field effect transistors appeared. Field effect transistors are no longer exotic components, however, and can be found more and more often in computer processors. For this reason, we feel the subject of field effect transistors is just as important as the subject of bipolar transistors. We choose the one easier to deal with, and this is certainly the field effect transistor.

In contrast to bipolar transistors and to diodes, field effect transistors are based on electrical phenomena only. They can be described solely by means of electricity.

The explanation of the bipolar transistor depends on an understanding of the diode, but even when diodes are understood, the explanation of the functionality of the bipolar transistor remains unsatisfactory. The explanation of the operating mode of a device should give students the feeling that they could have invented it themselves. We believe that this would never happen with the bipolar transistor.

Some elder teachers regret the time when we still had the good old triode tube, which was much easier to explain than the (bipolar) transistor. No current flows in the tube’s grid. In order to control the anode current, only the potential of the grid needs to be changed. Now, the field effect transistor is even simpler, because no cathode needs to be heated. It might be said that a field effect transistor is the ideal realization of a switch which can be opened and closed by changing an electric potential value.

The fact that the current can be controlled by altering the gate-potential results in a simplification of circuits. We need fewer resistors so the circuits become simpler.

We have not gone into any applications of transistors working as amplifiers. This would be too complicated because characteristic curves would need to be discussed. In most applications, namely all applications of digital electronics, transistors work simply as switches.

8. Literature

LAUKENMANN, M.: Dissertation, Universität Karlsruhe, 1995.

32. Nuclei

1. The analogy between nuclear physics and chemistry

There is an analogy between nuclear physics and chemistry or between the physics of the nucleus and the physics of the atomic shell which is farther reaching than text books ever let on. It often happens that concepts which are already known in chemistry are reintroduced in nuclear physics and even given new names. Processes already dealt with in chemistry are reworked in nuclear physics and in such a way that the similarity to what has already been discussed in chemistry class, is unrecognizable. Here are some examples:

The quantity called conversion rate in chemistry and measured in mol/s is called activity in nuclear physics and measured in Becquerels.

A chain reaction in nuclear physics is known as an autocatalytic reaction in chemistry.

The symbols used by these two fields for reaction equations are also different. In chemistry a reaction may be written as

$A + B \rightarrow C + D$

and in nuclear physics as

A(B,C)D,

a notation that suggests that the two educts A and B play different roles and that the products C and D do as well. The origin of this unfortunate notation is easy to recognize. It stems from the time when nuclear reactions were understood to be element conversions involving radiation, and radiation particles were not considered reaction partners.

The exponential decrease of an amount of excited nuclei or nuclei which are decaying has an analog in the decay of excited states of the atomic shells or in the decrease of the concentration of a chemically decaying substance.

The field of nuclear physics was especially zealous about inventing its own names for special processes. Decay, fission and fusion reactions are therefore represented as fundamentally different processes. This only obscures the fact that all of these can be described with the same tools.

2. Relics of historical development

The complicated historical development which finally led to the rather simple subject called nuclear physics has left a strong mark on teaching. In the classroom, many historical detours are repeated and superfluous concepts—which can only be understood from this historical context—are introduced.

The discovery of a new kind of radiation led to the first steps in nuclear physics. This happened at a time when radiation, in general, was a fashionable subject for physics research. Understandably, a newly discovered type of radiation received its name even before it was identified. This explains why, even today, we speak of α, β and γ radiation even though we know what is actually being discussed: Fast moving helium nuclei, fast moving electrons, and electromagnetic radiation. Each of these three substances is nothing more than one of the reaction products of certain nuclear reactions. However, there are many other such products of nuclear reactions that are not honored by a Greek letter.

3. Radiation detectors

When nuclear physics is taught, there is usually a lot of time spent explaining how radiation detectors work. We do not believe that this subject is important enough at the middle school level. There are numerous other more important measurement devices such as quartz clocks, thermocouples, infrared sensors, and many others which students do not learn much about.

4. Experiments with alpha-, beta- and gamma rays

In teaching nuclear physics, it is usual to investigate the properties of various types of radiation. The electric charge of the particle and the range covered by the radiation in various materials is a part of this.

As a justification for doing this one may assert that these are important questions. For one, they give information about the nature of an on-going nuclear reaction. They also are important for understanding the biological effects of radiation. We believe the reason is actually more historical. When the field of nuclear physics was in its infancy, radiation was the only thing known about it.

It should be remembered that most of the reaction products of nuclear reactions cannot be detected in classroom experiments anyway.

As to investigating the range of radiation, there are numerous other types of radiation we don't care about the ranges of. Wouldn't it be at least as interesting to investigate the range of infrared radiation, X-ray radiation, or microwaves?

5. Nuclear matter

The Karlsruhe Physics Course makes use of a model by applying it to the most varied situation. This is the model of continuously distributed substances. It allows us to imagine electric fields, magnetic fields, light, electrons ("electronium"), as well as the extensive (substance-like) physical quantities as a substance.

It is reasonable to deal in the same way with the material an atomic nucleus is made up of. In doing so, we emphasize that the substance is homogenous, that the protons and neutrons in the nucleus are not separate from each other. It would also seem reasonable to give this substance its own name: nucleonium. However, we have refrained from doing so because it would not be used much in class and at this point we value the gain in being economical with terms and concepts more highly.

6. The shape of excited nuclei

We interpret the traditional probability density of atomic shells as the density of electronium. In the same way we interpret the "probability density" of the nucleons or their constituents as the density of the nuclear matter. The distribution of this density determines the size and shape of the nucleus. As a consequence, excited nuclei are not described as oscillating or rotating drops as they are in the drop model. Instead, an excited nucleus has a fixed shape which is constant in time, just as other stationary states have. Each shape a nucleus locks into has a different energy.

7. Size and density of the atomic shell and of the nucleus

The density distributions of atomic shells are very different from those of atomic nuclei.

The electronium density of an atomic shell decreases strongly moving outward. The density of the nucleus is, by contrast, almost constant.

The nuclei and the shells behave very differently when going from atoms of lower to atoms of higher atomic numbers. For instance, a gold atom has about the same size as a lithium atom. This naturally means that the electronium density of gold atoms is very different from that of lithium atoms. Things are very different with nuclear material. In this case, the density for all atomic nuclei is pretty much the same. This means that the nuclear volume is simply proportional to the number of nucleons.

8. Binding energy or separation energy

We believe that the expression "binding energy" leads to difficulties in understanding. It suggests energy that is used for binding the parts of a nucleus. In fact, it is the energy emitted in the process of binding. This means that the binding energy of a nucleus is energy that the nucleus does not have. Is it negative energy then? In order to avoid such questions we use the name "separation energy." This is the energy used for separating the parts of the nucleus from each other. In this case, it is clear that the energy is positive.

Moreover, this name is formed analogously to the term "ionization energy" which is the energy needed to ionize an atom.

9. Table of separation energies

The binding energies of nuclei must be known in order to predict whether a nuclear reaction can take place or, more exactly, in which direction it can run. Students should have a table with the appropriate values available to them. There are various ways of creating such a table. Lists can be made of:

– the rest energies of the nuclei of nuclides;

– the binding energies per nucleon;

– the separation energies (the energy needed for fully decomposing a nucleus into its protons and neutrons).

We have chosen the third possibility. Although the first one, working with rest energies, is the simplest method conceptually, it has the disadvantage that its values are numbers with lots of digits. In every balance, differences of two large numbers appear. This is not an economical method.

We have refrained from using the second method using binding energies per nucleon (or separation energies per nucleon) because the quantities seem too unclear. When a nucleus is deconstructed, this is usually done in steps and a different separation energy is needed for each nucleon being separated from the nucleus.

Therefore, our table contains the total amount of separation energy which must be added to a nucleus to fully decompose it into protons and neutrons.

10. The determinative "anti"

The name antiparticle expresses a relationship. A certain particle is the antiparticle to another one. The antiproton is the antiparticle to the proton, and the proton is the antiparticle to the antiproton. The word antiparticle has a similar definition to the word "partner". One partner alone does not exist and there is only one partner for something (or someone) else.

But the determinative "anti" also has an absolute meaning when it stands before the name of a particle as in the cases of antiprotons, antineutrons, antineutrinos...

11. Names of classes of particles

New specialized terminology comes with the creation of a new field. The more such specialized expressions there are, the more shortly something can be expressed. However, the more such expressions there are, the more definitions must be learned.

In the subject of nuclear physics, there is a pronounced proliferation of names used for classifying particles. Each particle has its own name. Some even have two: One original and one that expresses its property as anti-partner. Positron and anti-electron is an example. In addition, particles are grouped together in classes.

They are called hadrons when they participate in strong interaction. When certain quantum numbers (baryon numbers and lepton numbers) have certain values, they are called baryons, mesons, leptons, particles or antiparticles. Baryons (and their antiparticles) participating in the formation of atomic nuclei are called nucleons.

Of all the names of classes of particles mentioned here, we only use particle and antiparticle. We do not need the name meson because reactions where mesons participate are not being covered. The name hadron is not used because we do not work with strong interactions. We have also not used the names nucleon, baryon and lepton.

12. Baryon number and lepton number

In order to find out whether or not a nuclear reaction is possible, we check to see if baryon number and lepton number are conserved in the reaction. There is a conservation law for each of the substance-like quantities called baryon and lepton numbers. The names baryon number and lepton number do not make it obvious that they are referring to substance-like quantities, or any physical quantity at all. These names suggest numbers of baryons or leptons. In fact, these quantities have negative values for some particles so they cannot represent numbers.

We prefer the names baryonic charge or leptonic charge. These names have been formed analogously to electric charge which students have had a lot of exposure to. Therefore, the fact that these quantities can take negative values seems normal.

One difference to electric charge is that baryonic and leptonic charge do not have units so that their values are always given in multiples of baryonic and leptonic elementary charge. To make the analogy with electric charge clear in spite of this, we occasionally give the values of electric charge in multiples of the elementary charge, as seen in Table 32.3.

13. Antimatter

So-called antimatter is often seen as a mysterious phenomenon of science fiction stories where the impression is given that it is the total opposite of matter. The question of whether it might have negative mass is often discussed. The name antimatter, which is unfortunately here to stay, certainly contributes to this. For this reason, we particularly emphasize that the difference between particles and antiparticles lies only in the signs of some physical quantities. Instead of giving the impression that an antiparticle is a negation of its corresponding particle, we try to give the impression that a particle and an antiparticle form a pair of two particles that are similar in many ways.

14 . Nuclear reactor and fusion reactor

Usually these installations are described in a way that makes them appear like very peculiar and tricky methods for two fundamentally different nuclear reactions to "release" energy.

In contrast, we try to introduce the two reactor types as something very similar. Nuclear reactions take place in both of them and for the same reason: Because the rest energy of the reactants is higher than that of the products. However, the reactions in both of these reactors are strongly inhibited because the reaction resistance is so high that the reactions cannot take place under normal conditions. In order to accelerate the reaction, a method used in chemistry is applied. Neutrons are used as catalysts in the nuclear reactor. In a tokamak fusion reactor, the reaction is accelerated by raising the temperature. Nuclear fusion can also be catalytically accelerated using muons.

15. The sun

Because the Sun is so important to what happens on Earth, one might assume that it would be given special emphasis in teaching the natural sciences. However, this is not the case. It is often represented as a kind of lamp lighting up what ever is going on here on Earth. All the same, now and then it is actually dealt with as an important energy source.

Again, the reasons for such a mistaken view of the value of this subject are historical. Our knowledge about the processes within the Sun is still relatively new and is a result of work done in the fields of advanced nuclear and particle physics. This has led to the belief that any statements that can be made about the Sun are difficult and can only be understood at an advanced level. This is absolutely untrue. Work done on the physics of the Sun have lead to results that are very simple:

– The density distribution of the Sun is very interesting and easy to teach.

– It is surprisingly easy to explain the reason the Sun is as hot as it is. Comparing the Sun to a hydrogen bomb gives the erroneous impression that the Sun is hot for the same reason a bomb explosion is. In fact, the reactions in the Sun differ from those of a hydrogen bomb because they take place extremely slowly. This is why the Sun has existed for so long.

– It is often suggested that the heat production processes within the Sun can only be understood if the Bethe-Weizsäcker cycle is understood. In chemistry, by contrast, one is usually content with a net reaction. Who knows what individual reactions take place during the burning of gasoline?

16. Nuclear reactions and chemical reactions

There are certain important questions which arise in nuclear physics just as they do in chemistry. A certain reaction is being considered and the first question asked is whether the reaction can take place and, if so, how fast. To answer these questions chemistry and nuclear physics proceed very similarly. Since it is often not made clear in the treatments of these subjects, we contrast the methods of chemistry and nuclear physics.

Setting up the reaction equation

Certain rules must be followed in setting up a chemical reaction equation. The numbers of atoms for each kind of element on the left side of the equation must be equal to those on the right side. In the vocabulary of physics, this is to satisfy a conservation law. In fact, in chemical processes, it is the numbers of atoms which is to be conserved. This is no general conservation law. It only holds for chemistry, and because of its lack of generality, it is not formulated as such.

Indeed, we often work in physics with quantities that are conserved only in a limited sense. We often make use of the conservation of mechanical energy in dissipation free processes in mechanics. Entropy can be considered a conserved quantity in many thermodynamic processes such as air movement in the atmosphere. Even for quantities whose general conservation we are currently convinced of, we should be prepared for the possibility that one day processes may be discovered where they are not conserved. An example of this is the baryonic number. It was always considered a strictly conserved quantity: No proton decay with baryonic conservation violation has ever been observed. Despite this, the search is on to find such processes which are allowed by theory.

It is therefore legitimate to speak of the conservation of the numbers of atoms in chemical processes.

One other conservation law should be taken into account when setting up a reaction equation, namely the conservation of electric charge.

One proceeds very similarly when setting up a nuclear reaction equation. The numbers of atoms of the elements are not conserved, but other conservation laws are valid instead. These conservation laws allow us to set up the equation. The conservation laws of nuclear physics are those of electric charge, baryonic number and leptonic number (or electric, baryonic and leptonic charge).

What direction can the reaction run in?

In chemistry, the chemical potential of reactants and products are compared. The reaction runs by itself from a higher to a lower chemical potential.

This can be done with nuclear reactions as well. In chemistry we arbitrarily choose as many zero points of the chemical potentials as there are chemical elements. In nuclear reactions, by contrast, one must operate with the absolute values of chemical potentials. The reason for this is that chemical elements can transform into each other.

Now the absolute values of chemical potentials can be well approximated to the molar rest energy of a substance. The difference of chemical potential in a nuclear reaction is essentially equal to the difference of the molar rest energies of the substances on the left and right sides of the reaction equation. Only under extreme conditions of very high temperature or high pressure do deviations result. Therefore, it is also possible to calculate the direction of the reaction using the rest energies instead of the chemical potentials.

We have had the choice of these two methods. The advantage of using chemical potential is that the method is identical to the one used in chemistry. However, we have decided to use rest energies instead. Chemical potential seems like a natural quantity if one is considering a reaction of very many particles (as is almost always done in chemistry). In contrast, the conversion rates in nuclear physics are very small and elementary reaction processes take center stage. Using the energy balance to decide the direction of a reaction is obvious because the conservation of substance-like quantities plays a big role in the discussion of nuclear reactions. The energy balance of a reaction is simply another balance along with electrical charge, baryonic numbers and leptonic numbers. Unfortunately, in doing things this way, one does not see that entropy is produced in a reaction taking place by itself, and that it is entropy production which is the actual drive of every such process.

Conversion rates

The conversion rate in chemistry indicates, in mol/s, how productive a reaction process is. Such a measure is needed for nuclear reactions as well. Unfortunately, another concept called activity has taken root here. Admittedly, activity is only used to describe one certain type of reaction, so-called radioactive decay (written in the symbols of chemistry as $A \rightarrow B + C$). Mole per second is not used as the unit either, but the Becquerel or the number of decays per second.

We prefer to use the term conversion rate. Becquerel appears as a smaller unit of the same physical quantity. We use a second unit in nuclear physics since conversion rates are commonly so small that even the determinatives "pico" and "femto" do not suffice.

Still another measure used in nuclear physics to specify the conversion rate of a reaction is half-life. Using the symbols n for the amount of the decaying substance, dn/dt for the conversion rate, and $T_{1/2}$ for the half-life, we obtain

$$\frac{dn}{dt} = -n \cdot \frac{\ln 2}{T_{1/2}}$$

Introducing half-life easily gives the impression that this quantity is something characteristic of nuclear physics and that the related exponential decay of an amount of substance is also exclusive to it. In order to avoid this we already introduce the concepts of half-life and exponential decay in our treatment of atomic physics. Indeed, the transformation of the atomic shell from an excited state to the ground state is actually the same kind of process the nucleus goes through from its excited state to its ground state.

17. The nuclide map

It might be surprising that we introduce the nuclide map so early. Students certainly cannot know where the numerous different nuclides can be found in nature. They will also hear that most nuclides are unstable. How do they come to exist at all? If students pose this question, the answer can be put off till later. They can be told that many molecules are unstable as well and that one normally does not worry about that in chemistry either. If they ask how these molecules come to be, the answer is that they are synthesized in many ways. This happens mostly in nature, and to a much smaller extent, in laboratories or factories. Very few synthesis processes are dealt with in chemistry class. This is similar for atomic nuclei. Unstable nuclei are produced in the most various ways, both natural and artificial. Some of these processes are covered in class.

18. Stable and unstable nuclides

The question of what is a stable nuclide is, to some extent, a matter of choice. Some nuclides, mostly the light ones, cannot decay. Every reaction that conserves electric charge, baryonic and leptonic number, leads to reaction products whose rest energy is higher than that of the reacting atomic nucleus. Such a reaction is impossible without the supply of energy, meaning it does not happen "by itself." Many other nuclides that are classified as stable on the nuclide map are, in this sense, not actually stable at all. They do not decay simply because the reaction resistance is very high. In other words, their half-life is very, very long.

III

Solutions to problems

1. Energy and energy carriers

Section 1.2

1. Incandescent bulb, electric motor, hair dryer, electric oven.

2. Electric motor, water turbine, wind turbine, gasoline engine.

3. Refundable-deposit-bottle energy carriers: Electricity, water in central heating unit, oil in hydraulic system. One-way-bottle energy carriers: Gasoline, compressed air, light.

Section 1.3

1. Light - electricity; moving air - electricity.

2. Electric oven; water turbine.

3. (Coal) - coal fired power plant - (electricity) - electric motor - (angular momentum) - water pump - (moving water).

4. Fig. 1.1

5. Dynamo; Fig. 1.2.

6. Dynamo - electric motor; incandescent bulb - solar (PV) cell; water turbine - water pump.

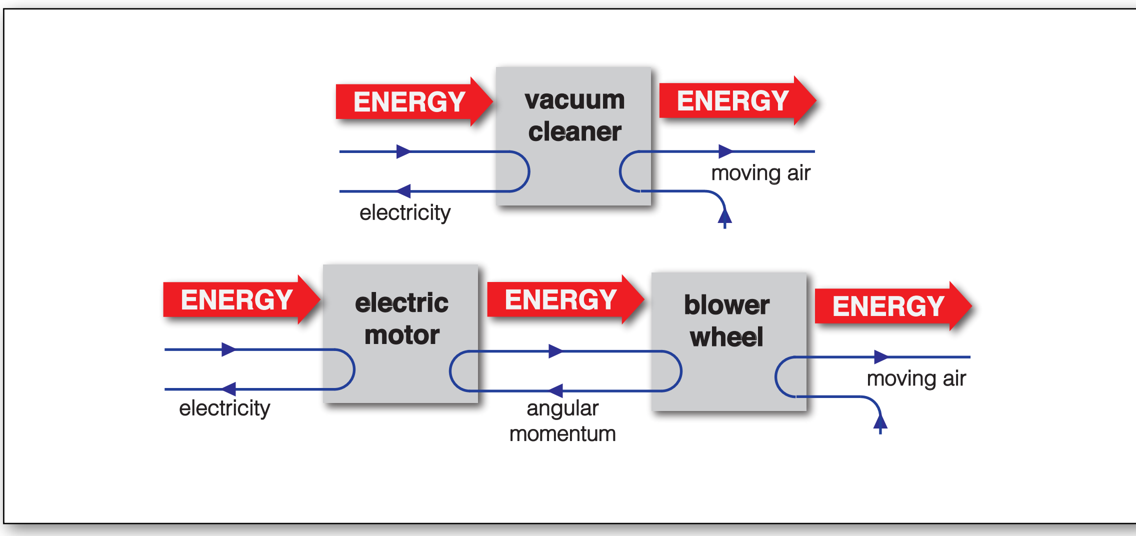

Fig. 1.1
Section 1.3, Problem **4**

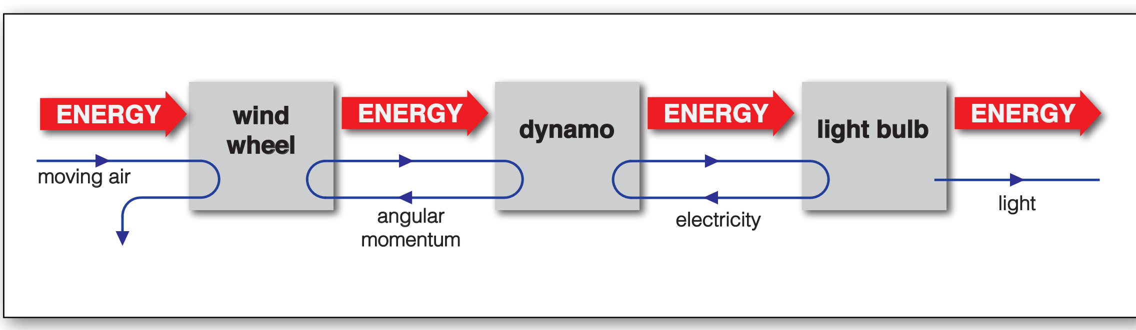

Fig. 1.2
Section 1.3, Problem **5**

Section 1.4

The energy current flowing into the device is equal to 500 Joule per second at level 1, and 1000 Joule per second at level 2.

2. Flows of liquids and gases

Section 2.2

2. 1 bar.

Section 2.3

(a) Air flows from the small into the large tire until the pressures are equal (pressure equilibrium).

(b) The pressure reached is closer to 1 bar.

(c) In the larger tire.

Section 2.5

1. 6 l/min.

2. Apart from the current, the flow speed also depends upon the cross section of the pipe.

3. 10 m^3/s.

Section 2.6

(a) 10 l/s as well. All the water flowing in on the left must flow out on the right.

(b) The resistance of the section between the narrowing and the right end is smaller than that between the left end and the narrowing. This is because the section on the right is shorter and wider. A smaller driving force (a smaller pressure difference) suffices for the same current to flow through the right section.

3. Momentum and momentum currents

Section 3.1

1. Length (l), meter (m); Area (A), square meter (m^2); Energy current (P), Watt (W); electric current (I), Ampere (A).

2. E = 12 MJ; v = 1.5 km/s; p = 110 kPa.

3. v = 20 m/s.

4. Calorie, horsepower.

Section 3.2

1. Total momentum: 1 500 Hy. Each car contains 300 Hy.

2. Before the collision: Two cars each contain 6 000 Hy, the third has 0 Hy. After the collision: Each car contains 4 000 Hy.

3. 10 Hy go from the left glider to the right glider. After the collision, the left glider has – 5 Hy, and the right glider has + 5 Hy.

4. Total momentum: (500 – 200) Hy = 300 Hy. After the collision, each car has + 100 Hy. The cars move to the right.

5. Momentum after the impact: –1 Hy. Difference of momentum: 2 Hy. 2 Hy flowed via the wall into the Earth.

Section 3.4

1. Two joined rods. When you pull, they separate.

2. The car continues to slide, it keeps its momentum. Normally, the contact between tire and street must conduct momentum. On ice it does not conduct momentum. Therefore, momentum cannot flow into the ground.

3. The wheels spin. Since the contact between wheels and street does not conduct momentum, momentum cannot be pumped by the engine into the car.

Section 3.5

1. Moving air gives momentum to the boat.

2. Momentum flows back to the water via the boat's hull. There is friction between the hull and the water.

Section 3.6

1. (a) The engine pumps momentum from the ground into the car. (b) Momentum slowly flows into the air and the earth. (c) Momentum quickly flows into the earth. (d) All the momentum pumped into the car by the engine flows into the air and the ground.

2. Momentum flows neither in nor out.

Section 3.8

1. Negative momentum flows from the car into the earth, i.e., positive momentum flows from the ground into the car. The speed of the earth is 0 m/s, the speed of the car is negative. The speed of the car is smaller than that of the earth. Therefore, momentum flows from the body having the higher speed to the body having lower speed. This agrees with our rule.

2. Negative momentum of the car increases, i.e., positive momentum decreases. Positive momentum flows out of the car through the arms of the person into the earth. Momentum flows to the right through the arms.

3. The coupling is under tension, see Fig. 3.1.

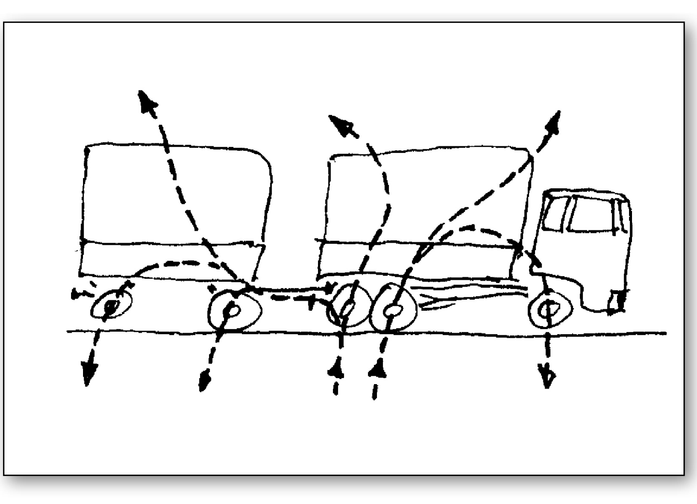

Fig. 3.1
See Section 3.8, Exercise **3**

Section 3.9

1. Momentum flows out of the earth through the back wheels of the tractor and from there through the rope to the tree and back into the earth.

2. Momentum flows out of the ground into the pole on the right, up through the pole to the clothesline, through the line to the left pole and down back into the earth. The line is under tension, and there is compressional stress in the ground.

3. A rotating ring in outer space. In nature: Saturn's rings, or the spinning Earth.

Section 3.10

1. $F = p/t$ = 200 Hy/10 s = 20 Hy/s = 20 N

2. $p = F \cdot t$ = 6000 N · 5 s = 30 000 Hy

3. F_C = 400 N, F_D = 600 N

4. From left crate: 100 N; from right crate: 200 N.

5. $p(t)$ is a straight line through the origin.

Section 3.12

1. $s = F/D$

a) s = 12 N/(150 N/m) = 0.08 m

b) s = 24 N/(150 N/m) = 0.16 m

2. a) F = 15 N: s = 0.32 m;
F = 30 N: s = 0.4 m.

b) s = 0.2 m: F = 4 N.

c) The greater the lengthening, the harder it is to stretch the rope further.

3. The ends of a thread are tied to the ends of a spring. The thread must hang loosely. If we pull this arrangement, momentum first flows through the spring according to Hook's law. As soon as the thread is taut, the setup cannot be stretched any further. The momentum current increases without the thread (and the spring) stretching any further.

4. We label the springs A and B. We have $F_A = D_A s_A$ and $F_B = D_B s_B$. Since the same momentum current flows through both springs, we have $F_A = F_B$, or $D_A s_A = D_B s_B$. Since $s_A = 4 s_B$, we have $D_B = 4 D_A$.

Section 3.13

Use twenty strings in parallel. The cross section of the momentum conductor will be 20 times that of a single string. No more than 100 N will flow through each string.

Section 3.14

1. Given: t = 40 min = 2/3 h
s = 10 km

Wanted: v

$$v = \frac{s}{t} = \frac{10\,\text{km}}{2/3\,\text{h}} = 15\,\text{km/h}$$

2. Given: t = 92 min = 92/60 h = 1.533 h
s = 185 km

Wanted: v

$$v = \frac{s}{t} = \frac{185\text{ km}}{1.533\text{ h}} = 120.7\text{ km/h} = 120.7 \cdot 0.2778\text{ m/s} = 33.5\text{ m/s}$$

3. Given: t = 10 min = 1/6 h
v = 90 km/h

Wanted: s

$v = s/t \Rightarrow s = v \cdot t$ $\quad s$ = 90 · (1/6) km = 15 km

4. Given: v = 800 km/h
s = 1600 km

Wanted: t

$v = s/t \Rightarrow t = s/v$

$$t = \frac{1600\,\text{km}}{800\,\text{km/h}} = 2\,\text{h}$$

5. Given: v = 300 000 km/s
s = 150 000 000 km

Wanted: t

$$t = \frac{150\,000\,000\,\text{km}}{300\,000\,\text{km/s}} = 500\,\text{s} \approx 8\,\text{min}$$

Section 3.15

1. Given: m = 12 t = 12 000 kg
v = 90 km/h = 25 m/s

Wanted: p

$p = mv$ = 12 000 kg · 25 m/s = 300 000 Hy = 300 kHy

2. Given: v = 20 m/s
m = 420 g = 0.42 kg

Wanted: p

$p = mv$ = 0.42 kg · 20 m/s = 8.4 Hy

3. Given: v = 30 m/s
m = 50 g = 0.05 kg

$p = mv$ = 0.05 kg · 30 m/s = 1.5 Hy

This is the momentum of the ball before the collision. Since it recoils from the wall, it has – 1.5 N after the collision. The wall took the difference

1.5 Hy – (– 1.5 Hy) = 3 Hy.

4. Given: m = 150 kg
F = 15 N
t = 5 s

Wanted: v

$F = p/t \Rightarrow p = F \cdot t$ = 15 N · 5 s = 75 Hy

$p = mv \Rightarrow v = p/m$ = 75 Hy/(150 kg) = 0.5 m/s

5. Given: F = 200 kN = 200 000 N
t = 30 s
v = 54 km/h = 15 m/s

Wanted: p, m

$p = F \cdot t$ = 200 000 N · 30 s = 6 000 000 Hy = 6 MHy

$p = mv \Rightarrow m = p/v$

m = 6 000 000 Hy/(15 m/s) = 400 000 kg = 400 t

6. Given: m = 42 kg
F = 20 N
t = 3 s
v = 1.2 m/s

$p = F \cdot t$ = 20 N · 3 s = 60 Hy

60 Hy flow into the car in 3 s.

$p = mv$ = 42 kg · 1.2 m/s = 50.4 Hy

The difference of 9.6 Hy must have flowed into the earth due to friction.

7. Given: Diameter of pipe d = 0.1 m
Length of pipe l = 2 km = 2000 m
v = 0.5 m/s
t = 2 s

Calculation of the volume in liters:

$V = \pi (d/2)^2 l = \pi (0.05)^2 \cdot 2000\ m^3 = 15.708\ m^3$ = 15 708 l

Since 1 l of water has a mass of 1 kg, we have

m = 15 708 kg.

$p = mv$ = 15 708 kg · 0.5 m/s = 7 854 Hy

Momentum flows through the valve into the earth. Calculation of the momentum current (force acting on the valve):

$F = p/t$ = 7854 Hy/2 s = 3927 N

4. The gravitational field

Section 4.3

1. Given: $m =$ (z.B.) 40 kg
$g_{Earth} = 10$ N/kg,
$g_{Moon} = 1.62$ N/kg
$g_{NS} = 1\,000\,000\,000\,000$ N/kg

Wanted: F

$F = m \cdot g$

Earth: $F = 40$ kg $\cdot$ 10 N/kg = 400 N

Moon: $F = 40$ kg $\cdot$ 1.62 N/kg = 64.8 N

Neutron star: $F = 40$ kg $\cdot$ 10^{12} N/kg = 40 000 000 000 000 N

2. Given: $F = 300$ N
$g = 1.62$ N/kg

Wanted: m

$F = m \cdot g$

$\Rightarrow m = F/g = 300$ N/1.62 (N/kg) = 185.2 kg

Section 4.4

1. Given : $m =$ (e.g.) 40 kg
$t = 0.77$ s

Wanted: p, v

$p = m \cdot g \cdot t = 40$ kg $\cdot$ 10 N/kg $\cdot$ 0.77 s = 308 Ns = 308 Hy

$v = g \cdot t$ = 10 N/kg $\cdot$ 0.77 s = 7.7 m/s

2. Given: $t = 0.5$ s
g_{Earth}, g_{Moon}, g_{Sun}

Wanted: v

$v = g \cdot t$

$v_{Earth} = 5$ m/s, $v_{Moon} = 0.81$ m/s, $v_{Sun} = 137$ m/s

3. Given: $v = 15$ m/s

$v = g \cdot t$ $\Rightarrow t = v/g = 15$ (m/s)/10 (N/kg) = 1.5 s = Time to highest point

Total time $t_{tot} = 2 \cdot t = 3$ s

4. Given: $t_{tot} = 5$ s

time to fall down: $t = t_{tot}/2 = 2.5$ s

$v = g \cdot t = 10$ (N/kg) $\cdot$ 2.5 s = 25 m/s

Section 4.5

A momentum current of

$F = m \cdot g = 0.8$ kg $\cdot$ 10 N/kg = 8 N

flows from the earth into the sphere.

In Fig. 4.7, we read: $v = 20$ m/s

Section 4.6

1. The astronaut sets the object in motion so that they move at equal speeds. He needs more momentum for the heavier objects.

2. The astronauts start the engines. Momentum flows from the rocket into the astronauts. The momentum current is felt as “gravity” or “weight”.

Section 4.7

1. Given: $V = 1.6$ l
$m = 1.3$ kg

Wanted: ρ

$\rho = m/V = 1.3$ kg/0.0016 m^3 = 812.5 kg/ m^3

2. Given: $m = 2.2$ kg
$\rho = 2600$ kg/ m^3 (from the Table)

Wanted: V

$V = m/\rho = 2.2$ kg/(2600 kg/ m^3) = 0.00085 m^3 = 0.85 l

3. Given: $V = 40$ l
$\rho = 720$ kg/ m^3 (from the Table)

Wanted: m

$m = \rho\, V$ = (720 kg/ m^3) $\cdot$ 0.04 m^3 = 28.8 kg

4. Given: $m = 8.2$ kg
$\rho = 8960$ kg/ m^3 (from the Table)
Length $l = 1.2$ m
Width $b = 0.8$ m

Wanted: Thickness d

$V = m/\rho = 8.2$ kg/(8960 kg/ m^3) = 0.000915 m^3 = 0.915 l = 915 cm^3

$V = l \cdot b \cdot d \Rightarrow d = V/(l \cdot b)$ = 915 cm^3/(120 cm $\cdot$ 80 cm)
= 0.095 cm = 0.95 mm

Section 4.8

1. Iron floats on mercury since the density of iron is smaller than that of mercury.

2. The balloon sinks. The density of carbon dioxide is higher than that of air.

5. Momentum and energy

Section 5.1

1. Given: $v = 20$ km/h $= 5.6$ m/s
$F = 900$ N

Wanted: P

$P = v \cdot F = 5.6$ m/s $\cdot$ 900 N = 5040 W

Momentum flows through the wheels to the ground. The energy is used up in the bearings and the tires as a result of heat production.

2. Given: $s = 35$ km
$F = 900$ N

Wanted: E

$E = F \cdot s = 900$ N $\cdot$ 35 km = 31 500 kJ

3. Given: $v = 10$ m/s
$P = 800$ W

Wanted: F

$P = v \cdot F \Rightarrow F = P/v = 800$ W/(10m/s) = 80 N

4. Given: $m = 50$ kg
$v = 0.8$ m/s
$h = 5$ m

Wanted: P, t, E

Force of gravity: $F = m \cdot g = 50$ kg $\cdot$ 10 N/kg = 500 N

$P = v \cdot F = 0.8$ m/s $\cdot$ 500 N = 400 W

$v = h/t \Rightarrow t = h/v = 5$ m/(0.8 m/s) = 6.25 s

$P = E/t \Rightarrow E = P \cdot t = 400$ W $\cdot$ 6.25 s = 2500 J = 2.5 kJ

Section 5.3

1. Energy: From the car to the spring of the buffer and from there back to the car.

Momentum: From the car through the spring of the buffer until the momentum has the same absolute value as at the beginning (but with opposite sign).

2. Energy: During fall, from the gravitational field into the ball. During impact with the ground, redistribution in the ball. During ascent: back into the gravitational field.

Momentum: During fall, from the Earth through the field into the ball. During impact: From the ball into the Earth. During ascent: From the Earth through the field into the ball.

3. Taking the lowest point as a reference:

Energy: Below the equilibrium point, energy goes from the rubber band into the gravitational field and the body. Above the equilibrium point, energy goes from the rubber band and the body into the gravitational field. The opposite is true for the part where the body moves downwards.

Momentum: Momentum always goes from the Earth through the gravitational field into the body. It always flows out of the body through the rubber band and the mounting back into the Earth. Below the equilibrium point, more momentum flows off through the band than is supplied by the field. That's why the momentum of the body becomes negative. Above the equilibrium point, less momentum flows off through the rubber band than flows in through the field. Therefore, the negative momentum of the body decreases. The opposite is true for the period during which the body moves downwards.

6. Momentum as a vector

Section 6.1

1. See Fig. 6.1

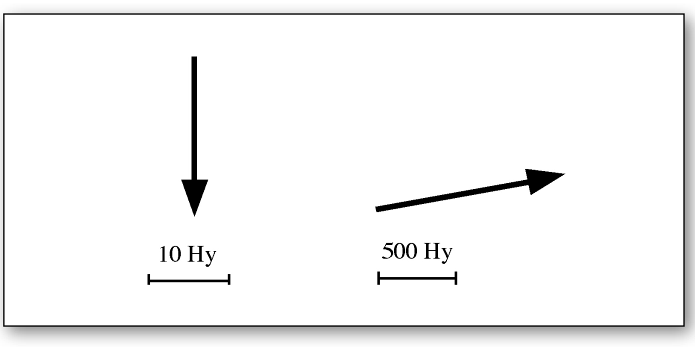

Fig. 6.1
See Section 6.1, Exercise **1**

2. See Fig. 6.2

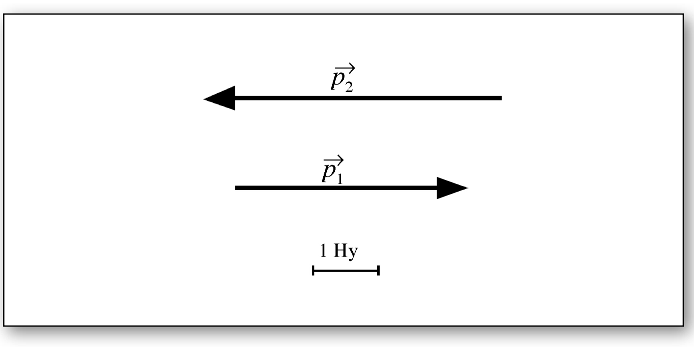

Fig. 6.2
See Section 6.1, Exercise **2**

3. Magnitude: 2400 Hy 900 Hy 2100 Hy
Direction: 210° 300° 180°

Section 6.2

1. Toward the trailer: Arrow for current points to the right. Away from the trailer: Arrow for current points to the left.

2. (a) 0°-momentum is flowing toward the wagon.
(b) The momentum current follows the spiral.
(c) The vector of the current points to the right.

3. (a) $F = m \cdot g$ = 0.3 kg · 10 N/kg = 3 N
(b) 270°-momentum
(c) The arrow points down.

Section 6.3

1. Given: m = 0.1 kg
$p_{\text{Beginning}}$ = 0.5 Hy
(a) The stone receives 0.1 kg · 10 N/kg = 1 Hy/s, i.e., 1 Hy in one second. It is 270°-momentum.
(b) Fig. 6.3

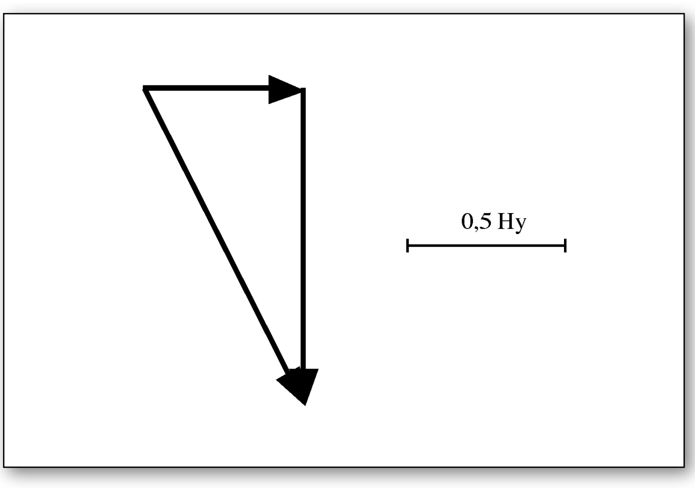

Fig. 6.3
See Section 6.3, Exercise **1**

(c)
$$p = \sqrt{(0.5\text{ Hy})^2 + (1\text{ Hy})^2} = 1.12\text{ Hy}$$

2. Given: m = 0.3 kg
v_{initial} = 5 m/s
(a) $p = m \cdot v$ = 0.3 kg · 5 m/s = 1.5 Hy
(b) If the stone moves at an angle of 45°, it has received 1.5 Hy from the Earth. The total momentum is therefore
$$p = \sqrt{(1.5\text{ Hy})^2 + (1.5\text{ Hy})^2} = 2.1\text{ Hy}$$

3. Given: m = 3 kg
p_{initial} = 12 Hy 45°-momentum
If the sphere has received momentum equal to
$$p = \sqrt{(12\text{ Hy})^2 + (12\text{ Hy})^2} = 17\text{ Hy}$$
from the Earth, it flies downward at an angle of 45°.
The momentum current is
$F = m \cdot g$ = 3 kg · 10 N/kg = 30 N.
Therefore, we have
$t = p/F$ = 17 Hy/30 N = 0,57 s

4. Given: m = 1 200 000 kg
v = 70 km/h = 19.4 m/s
$p = m \cdot v$ = 1 200 000 kg · 19.4 m/s = 23.3 MHy
See Fig. 6.4a

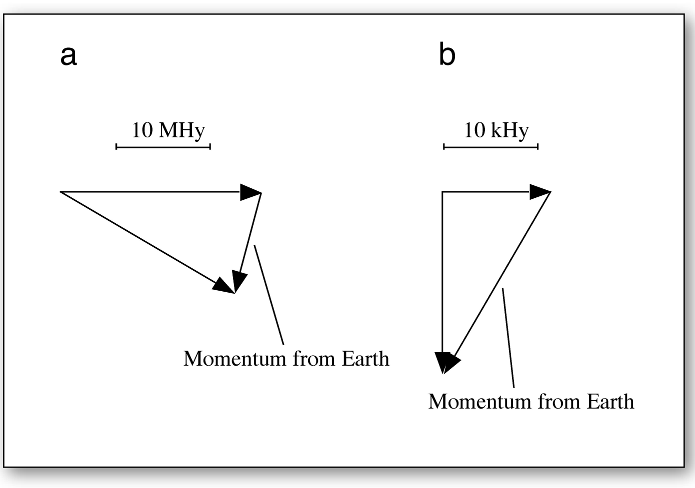

Fig. 6.4
See Section 6.3, Exercises **4** and **5**

5. Given: m = 1 400 kg
v_1 = 30 km/h = 8.33 m/s
v_2 = 50 km/h = 13.9 m/s
See Fig. 6.4b
p = 22 656 Hy (calculated)

6. The ball receives momentum from the goalie. During the flight it receives 270°-momentum from the Earth, and it looses momentum to the air. This momentum is of the type it has at each moment. Then the ball receives momentum from the player: Twice as much (by magnitude) as it had just before it arrived at the player's foot. The direction is opposed to the one it had before arrival.

Section 6.5

1. A direction of 0° is to the right. The connection does not conduct 0°-momentum, and it conducts 90°-momentum.

2. The connection does not conduct momentum that lies in the plane of the setup, and it conducts momentum that is perpendicular to the plane.

Section 6.6

1. Vector construction yields 17.5 N.

2. Vector construction yields 470 N.

Section 6.7

1. Vector construction yields 28 000 N.

2. Vector construction yields about 290 N for the momentum current in every rope. The ropes will tear.

7. Torque and center of gravity

Section 7.1

1. See Fig. 7.1

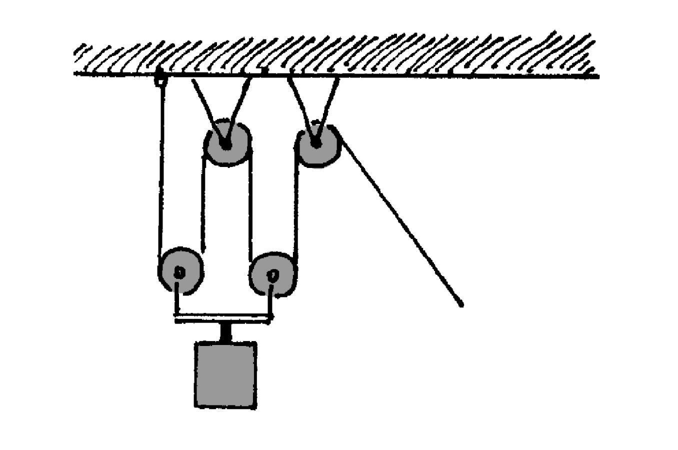

Fig. 7.1
See Section 7.1, Exercise **1**

2. F_L = 100 kg · 10 N/kg = 1000 N
F_Z = (1/4) · 1000 N = 250 N

3. The currents in the sloping ropes are very high. Therefore, the current in the rope which is pulled is very high too. We do not gain anything.

Section 7.2

1. The lower reel ascends by 1 m, the one in the middle by 2 m. Z has to be pulled by 4 m.

$E = s \cdot F$ = 1 m · 100 kg · 10 N/kg = 1000 J

2. The weight is lifted by 0.25 m.

E = 0.25 m · 20 kg · 10 N/kg = 50 J

3. Given: m = 200 kg
v_{left} = 0.2 m/s
v_{right} = 0.4 m/s

Wanted: F_{left}, F_{right}, P_{left}, P_{right}

Hoisting rope: $F_L = m \cdot g$ = 200 kg · 10 N/kg
= 2000 N

Pulling rope: $F_Z = F_L/4$ = 500 N = $F_{left} = F_{right}$

$P_{left} = v_{left} \cdot F_{left}$ = 0.2 m/s · 500 N = 100 W

$P_{right} = v_{right} \cdot F_{right}$ = 0.4 m/s · 500 N = 200 W

Section 7.3

1. Given: r_R = 25 cm
r_L = 5 cm
F_L = 50 N

Wanted: F_R

$F_R = F_L\,(r_L/r_R)$ = 50 N · 0.2 = 10 N

2. The points of support are called A (left) and B (right). A is chosen as the pivot.

Given: m = 9000 kg
a) r_R = 6 m, r_L = 12 m   b) r_R = 4 m, r_L = 12 m

$F_R = m \cdot g$ = 9000 kg · 10 N/kg = 90 000 N

a) $F_B = F_L = F_R\,(r_R/r_L)$
= 90 000 N · (6 m/12 m) = 45 000 N

$F_A = F_R - F_B$ = 90 000 N – 45 000 N = 45 000 N

b) $F_B = F_L = F_R\,(r_R/r_L)$
= 90 000 N · (4 m/12 m) = 30 000 N

$F_A = F_R - F_B$ = 90 000 N - 30 000 N = 60 000 N

3. Given: r_R = 5 cm + 15 cm = 20 cm
r_L = 5 cm
F_L = 80 N

Wanted: F_R

$F_R = F_L\,(r_L/r_R)$ = 80 N · 0.25 = 20 N

4. $F_R = m \cdot g$ = 120 kg · 10 N/kg = 1200 N

F_B = 1200 N · (80 cm/80 cm) = 1200 N

F_A = 1200 N · (160 cm/80 cm) = 2400 N

5. Given: r_R = 1.2 m + 0.4 m = 1.6 m
r_L = 0.4 m
F_R = 80 N

Wanted: F_L

F_L = 80 N · (1.6 m/0.4 m) = 320 N

6. The screw cannot be tightened so strongly by hand because the torque is smaller.

Section 7.4

1. Right torque = $r_R \cdot F_R$ = 2.1 m · 45 kg · 10 N/kg = 945 Nm

Left torque = $r_L \cdot F_L$ = 0.82 m · 150 kg · 10 N/kg = 1230 Nm

The rod is not in equilibrium, it turns counterclockwise.

2. Right torque = 1.5 m · 50 kg · 10 N/kg = 750 Nm

Left torque = 0.15 m · 250 kg · 10 N/kg = 375 Nm

She can do it.

Section 7.5

1. In the middle of the axis.

2. At the center of Earth.

4. The distance between center of gravity and center of moon r_M is 100 times the distance between center of gravity and center of Earth r_E. Therefore:

r_E = 380 000 km/101 = 3762 km.

The center of gravity is inside the Earth.

Section 7.6

2. The center of gravity is below the point of support of the cork. The equilibrium is stable.

Section 7.7

1. A sphere is able to roll on a horizontal plane. A car is able to roll on a horizontal plane. A wheel is able to spin around its axis.

2. The center of gravity of the tilting bicycle moves down, the cener of gravity of the car moves up.

3. No. The body moves in such a way that the lower right corner rolls down.

4. No. When tilting, the center of gravity would have to move upwards initially.

5. Equilibrium is established with the help of the weights. To determine the unknown mass, the mass of the weights is multiplied by the ratio of left to right lever arm. Advantage of this balance scale: We can work with smaller weights.

8. Angular momentum and angular momentum currents

Section 8.1

See Table 8.1

A body contains more momentum the higher the speed.	A body contains more angular momentum the higher the angular speed.
A body contains more momentum the greater its mass.	A body contains more angular momentum the greater its mass.
Momentum can be transferred from one body to another.	Angular momentum can be transferred from one body to another.
Momentum can be distributed among several bodies.	Angular momentum can be distributed among several bodies.
A car with bad bearings stops moving. Its momentum flows into the ground.	A wheel with bad bearings stops rotating. Its angular momentum flows into the ground.
Momentum can be positive or negative.	Angular momentum can be positive or negative.
The momentum of a body is positive if it moves to the right. It is negative if the body moves to the left.	Put your right hand around the axis of rotation so that the bent fingers indicate the direction of rotation. If the thumb points in the positive *x*-direction, the angular momentum is positive. If it points in the negative *x*-direction, the angular momentum is negative.

Table 8.1

Section 8.2

If the wheels spin in opposite directions initially, person and revolving chair stay at rest during braking. If they rotate in the same direction initially, person and revolving chair start rotating in the same direction as the wheels during braking.

Section 8.3

1. In the case of cars: To avoid the loss of forward momentum into the ground, and for driving. For energy transfer with transmission belts. For pulleys. For gears.

2. Steam engine, car engine, sewing machine, toy car, record player, cassette and video recorders.

3. It will brake apart. (During fast rotation, strong momentum currents flow in the wheel.)

Section 8.4

1. See Fig. 8.1a. The crank is turned inside the water vessel which is mounted so it can rotate. If water conducts angular momentum, the glass will start to rotate.

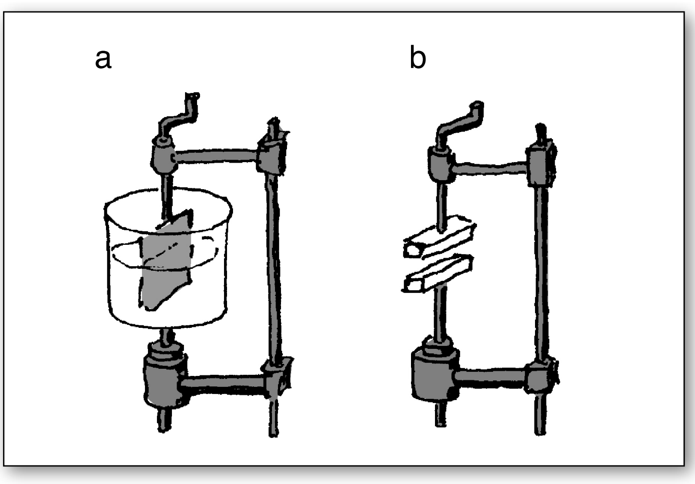

Fig. 8.1
See Section 8.4, Exercises **1** and **2**

2. See Fig. 8.1b. The crank is turned. The lower part rotates with the upper part.

3. Fig. 8.2. The left ventilator wheel starts turning.

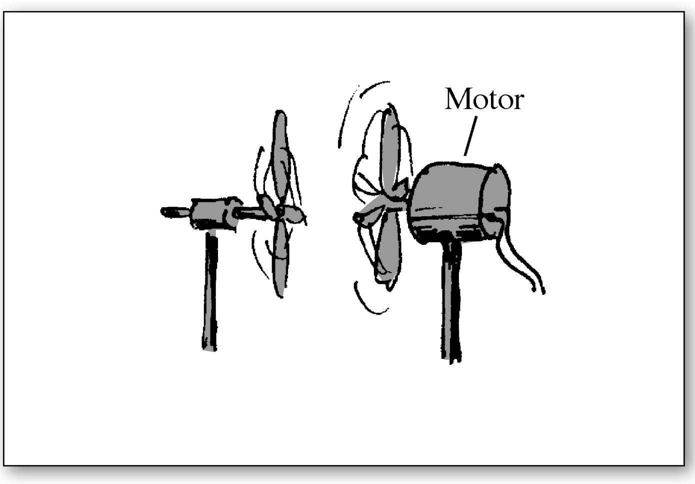

Fig. 8.2
See Section 8.4, Exercise **3**

4. Crankshaft, camshaft, drive shaft (cardan shaft).

5. Thick shafts can take stronger angular momentum currents than thin ones.

Section 8.5

1. From the engine shaft through the ventilator wheel, the air, the ground, the casing of the engine, and back to the engine shaft.

2. Right hand - pencil - sharpener - left hand - body - right hand.

Section 8.6

1. See Fig. 8.3

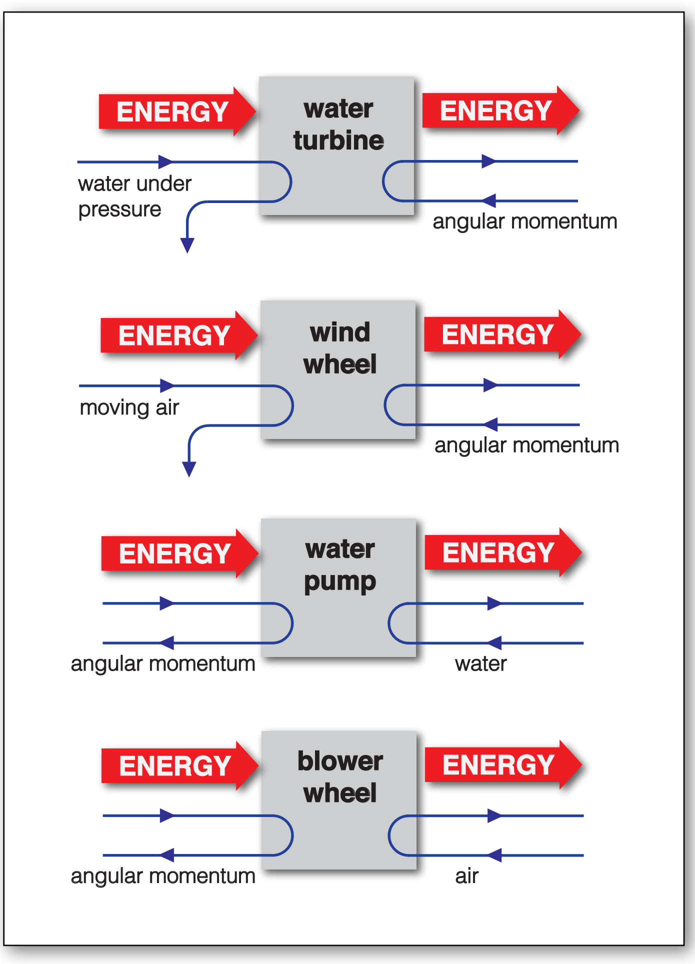

Fig. 8.3
See Section 8.6, Exercise **1**

2. All kinds of engines and turbines. They can be recognized by their rotating shafts that drive something else.

3. Drill, circular saw, coffee grinder, hedge shears. They are recognized by the shaft that drives them.

4. By a crank.

9. Compressive and tensile stress

Section 9.1

1. Given: $F = 420$ N

$A_1 = 2$ cm^2

$A_2 = 3$ cm^2

$A_3 = 3$ cm^2

Wanted: p_1, p_2, p_3

$$p_1 = -\frac{420\text{ N}}{0.0002\text{ m}^2} = -2.1\text{ MPa}$$

$$p_2 = p_3 = -\frac{420\text{ N}}{0.0003\text{ m}^2} = -1.4\text{ MPa}$$

2. Given: $m = 12$ kg

$A = 1.5$ cm^2

Wanted: p_1, p_2, p_3

$F_3 = m \cdot g = 12\text{ kg} \cdot 10\text{ N/kg} = 120$ N

$F_1 = F_2 = F_3/2 = 60$ N

$$p_1 = -\frac{120\text{ N}}{0.00015\text{ m}^2} = -800\text{ kPa}$$

$$p_2 = p_3 = -\frac{60\text{ N}}{0.00015\text{ m}^2} = -400\text{ kPa}$$

3. An estimate of the momentum current is $F = 40$ N. The diameter of the small nail is about

$d = 1$ mm^2.

The cross section equals

$$A = p\left(\frac{d}{2}\right)^2 \approx 0.8\text{ mm}^2 = 0.000\,000\,8\text{ m}^2$$

Therefore,

$$p = \frac{40\text{ N}}{0.000\,000\,8\text{ m}^2} = 50\text{ MPa} = 500\text{ bar}.$$

Taking the cross section of the tip to be 10 times smaller, there will be a pressure of 500 MPa = 5000 bar.

4. Taking the mass of of the hammer to be $m = 1$ kg and the speed $v = 2$ m/s, its momentum is $p = 1\text{ kg} \cdot 2\text{ m/s} = 2$ Hy. Assume the momentum transfer to take 0.01 s. Using $F = p/t$, we have

$$F = \frac{2\text{ Hy}}{0.01\text{ m}^2} = 200\text{ N}$$

If the cross section of the tip of the nail equals

0.1 mm^2 = 0.000 000 1 m^2,

the pressure will be

$$p = \frac{200\text{ N}}{0.000\,000\,1\text{ m}^2} = 2000\text{ MPa} = 20\text{ kbar}$$

Section 9.2

1. Textiles, cloth

2. Concrete, stone, sand, gravel

3. Wood, some textiles, mica, graphite

Section 9.5

1. Given: $h = 4$ m

$\rho = 1000$ kg/m^3

Wanted: p_S, p

$p_S = \rho \cdot g \cdot h = 1000\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 4\text{ m} = 40\,000\text{ Pa} = 0.4$ bar

$p = p_S + 1\text{ bar} = 1.4$ bar

2. Given: $h = 11\,000$ m

$\rho = 1000$ kg/m^3

Wanted: p_S

$p_S = 1000\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 11\,000\text{ m} = 110\,000\,000\text{ Pa} = 1100$ bar

3. Given: $h_1 = 0.5$ m

$h_2 = 0.3$ m

$\rho_1 = 1000$ kg/m^3

$\rho_2 = 13\,550$ kg/m^3

Wanted: p_S

$p_S = p_{S,1} + p_{S,2}$

$= 1000\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 0.5\text{ m} + 13\,550\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 0.3\text{ m}$

$= 5000\text{ Pa} + 40\,650\text{ Pa} = 45\,650$ Pa

Section 9.6

1. Water flows from the left to the right container until the levels are equal.

2. At the level of the connecting pipe, the pressures of water and alcohol must be equal.

$p_{S,Alcohol} = p_{S,Water}$

The hydrostatic pressure of alcohol is:

$p_{S,Alcohol} = 790\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 0.3\text{ m} = 2370$ Pa

Therefore, $p_{S,Water} = 2370$ Pa.

Using

$p_{S,Water} = \rho_{Water} \cdot g \cdot h_{Water}$, we have:

$$h_{Water} = \frac{p_{S,Water}}{\rho_{Water} \cdot g} = \frac{2370\text{ m}}{1000 \cdot 10} = 0.24\text{ m}$$

The level difference equals $h_{Alcohol} - h_{Water} = 7$ cm.

Section 9.7

1. Given: $\rho_{Hg} = 13\,550$ kg/m^3

$\rho_{Fe} = 7900$ kg/m^3

$V = 5$ cm^3

Wanted: $m_{Fe} - m_{Hg}$, F_A

$m_{Fe} = \rho_{Fe} \cdot V = 7900\text{ kg/m}^3 \cdot 0.000\,005\text{ m}^3 = 0.0395\text{ kg} = 39.5$ g

$m_{Hg} = \rho_{Hg} \cdot V = 13\,550\text{ kg/m}^3 \cdot 0.000\,005\text{ m}^3 = 0.06775\text{ kg} = 67.75$ g

$m_{Fe} - m_{Hg} = 39.5\text{ g} - 67.75\text{ g} = -28.25$ g

The piece of iron appears to be lighter by 67.75 g, it appears to have negative mass. Therefore, it does not sink, it moves upwards.

$F_A = m_{Hg} \cdot g = 0.06775\text{ kg} \cdot 10\text{ N/kg} = 0.6775$ N

2. Given: $m = 150\,000$ kg

$\rho_{Granite} = 2600$ kg/m^3

Wanted: m_{Water}, F_A

First, we calculate the volume of the granite boulder.

$$V = \frac{m}{\rho} = \frac{150\,000\text{ kg}}{2600\text{ kg/m}^3} = 57.7\text{ m}^3$$

The mass of the displaced water equals

$m_{Water} = \rho_{Water} \cdot V = 100\text{ kg/m}^3 \cdot 57.7\text{ m}^3 = 57\,700$ kg

The granite boulder appears to be lighter by 57.7 t .

$F_A = m_{Water} \cdot g = 57\,700\text{ kg} \cdot 10\text{ N/kg} = 577\,000$ N

3. Given: $m_{Stone} - m_{Water} = 1.4$ kg

$\rho_{Stone} = 2400$ kg/m^3

Wanted: m_{Stone}

First, calculate the volume of the stone:

$m_{Stone} - m_{Water} = \rho_{Stone} \cdot V - \rho_{Water} \cdot V = (\rho_{Stone} - \rho_{Water}) \cdot V \Rightarrow$

$$V = \frac{m_{Stone} - m_{Water}}{\rho_{Stone} - \rho_{Water}} = \frac{1.4\text{ m}^3}{2400 - 1000} = 0.001\text{ m}^3$$

$m_{Stone} = \rho_{Stone} \cdot V = 2400\text{ kg/m}^3 \cdot 0.001\text{ m}^3 = 2.4$ kg

4. When the piece of wood sticks out of the water, it displaces less water, its buoyant force will be smaller. It moves up until the buoyant force equals $m_{Wood} \cdot g$.

5. 1500 t

6. In sea water, the ship sticks out somewhat more.

Section 9.8

1. Some water gets into the glass and compresses the air. The air pressure rises until it is equal to the hydrostatic pressure of the water at the interface.

2. If the water did not rise there would be a space above the inside water surface having a pressure of 0 bar. The water will immediately be pressed into this space since its pressure equals 1 bar on the water surface on the outside.

3. If one moves upward in water, the hydrostatic pressure decreases. At its surface, the hydrostatic pressure of water is 0 bar. If one moves further up, the hydrostatic pressure will be negative. At point A we have

$p_{S,A} = -\rho_{Water} \cdot g \cdot 1\text{ m} = -1000\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 1\text{ m} = -10\,000$ Pa

The total pressure

$p_{Air} + p_{S,A} = 100\,000\text{ Pa} - 10\,000\text{ Pa} = 90\,000$ Pa

is still positive.

At B, the hydrostatic pressure is positive. The distance to the surface of the water is 1 m.

$p_{S,B} = \rho_{Water} \cdot g \cdot 1\text{ m} = 1000\text{ kg/m}^3 \cdot 10\text{ N/kg} \cdot 1\text{ m} = 10\,000$ Pa

The total pressure is

$p_{Air} + p_{S,B} = 100\,000\text{ Pa} + 10\,000\text{ Pa} = 110\,000$ Pa.

If the faucet is opened, water will flow since the outside pressure is only 100 000 Pa.

Section 9.9

1. Given: $p = 150\text{ bar} = 15\,000\,000$ Pa

$A = 5\text{ cm}^2 = 0.000\,5\text{ m}^2$

$v = 20\text{ cm/s} = 0.2$ m/s

Wanted: P, F

$F = A \cdot p = 0.000\,5\text{ m}^2 \cdot 15\,000\,000\text{ Pa} = 7500$ N

$P = v \cdot F = 0.2\text{ m/s} \cdot 7500\text{ N} = 1500$ W

2. Given: $p = 80\text{ bar} = 8\,000\,000$ Pa

$d = 1$ m

$P = 12$ MJ/s

Wanted: v

$A = \pi (d/2)^2 = 0.785$ m^2

$P = v \cdot A \cdot p \Rightarrow$

$$v = \frac{P}{A \cdot p} = \frac{12\,000\,000\text{ J/s}}{0{,}758\text{ m}^2 \cdot 8\,000\,000\text{ Pa}} = 2.0\text{ m/s}$$

10. Entropy and entropy currents

Section 10.1

1. There is more entropy in room A since air mass and temperature are higher.

2. Each cup gets 1/6 of the coffee, the pot still contains 3/6 of the coffee. So we have a quantity of entropy equal to

S_{Cup} = 3900/6 Ct = 650 Ct

in each cup, and

S_{Pot} = 3900/2 Ct = 1950 Ct

in the coffee pot.

Section 10.2

1. (a) The temperature of the burner is higher than that of the pot. (b) The temperature of the mat is lower than that of the pot. (c) Initially, the temperature of the table is higher than that of the bottle. Entropy flows from the table to the bottle, the temperature of the table goes down.

2. Entropy flows from the large block to the small one. The final temperature will be closer to 120°C than to 10°C.

Section 10.3

2. The heat pump pumps entropy from the interior of the refrigerator. An equal amount flows back in through the open door. (In electricity, the analogous situation is a short circuit.)

Section 10.4

1. 273.15 K; 298.15 K; 373.15 K; 90.15 K; 77.35 K; 4.25 K; 0 K.

2. – 259.2°C; – 252.8°C; – 218.8°C; – 210°C.

3. $S \approx 500$ Ct

Section 10.5

1. Light flows from the surrounding objects into the lamp. The battery will be charged slowly.

2. Water vapor and carbon dioxide flow into the exhaust pipe. The cooler cools the air flowing past it; as a result, the cooling water gets warmer. The engine emits a mixture of gasoline and air. In the carburetor, air and gasoline are separated. Fresh air leaves the engine through the air filter. The gas tank is filled slowly with gasoline.

3. Warm air arrives at the brake. The brake cools and the bicycle speeds up backwards.

Section 10.7

1. (a) The walls should be thick. (b) The total surface of the outer walls must be small, there should not be too many corners. (c) The walls must be made from a material having high thermal resistance.

2. (a) The material the radiator is made of must be thin. (b) The surface of the radiator (i.e., the cross section of the conductor) must be large. (c) The material should be a good conductor.

Other devices that depend upon good thermal conduction: the radiator of a car, the cylinder head of an air-cooled combustion engine, the heat exchanger at the back of a refrigerator.

Section 10.8

1. Losses as a consequence of conduction: through walls, closed windows and doors. Convective losses: Through cracks and leaks in doors and windows.

2. Convectively from the flame of the burning gasoline to the interior wall of the cylinder; by conduction through the cylinder walls to the cooling water; convectively with the cooling water from the motor to the radiator; by conduction through the pipe walls of the radiator; and finally, with the air into the surroundings (convection).

3. Entropy goes with the cooling water of the engine to a kind of radiator. From there, it enters air which is blown into the interior of the car.

11. Entropy and energy

Section 11.1

1. See Fig. 11.1

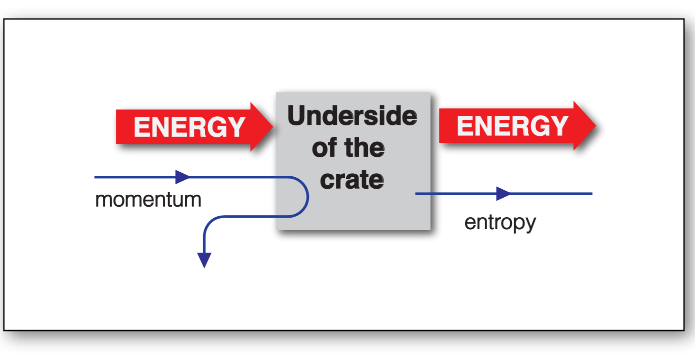

Fig. 11.1
See Section 11.1, Exercise **1**

2. Entropy is produced upon impact of the blocks on the ground. The energy comes from the gravitational field.

Section 11.2

1. Given: $T = (273 + 20)\text{K} = 293\text{ K}$
$I_S = 35\text{ Ct/s}$
Wanted: P
$P = T \cdot I_S = 293\text{ K} \cdot 35\text{ Ct/s} = 10\,255\text{ W} \approx 10\text{ kW}$

2. Given: $T = (273 + 90)\text{K} = 363\text{ K}$
$I_S = 60\text{ Ct/s}$
Wanted: P
$P = T \cdot I_S = 363\text{ K} \cdot 60\text{ Ct/s} = 21\,780\text{ W} \approx 22\text{ kW}$

3. Given: $T = (273 + 300)\text{K} = 573\text{ K}$
$P = 1000\text{ W}$
Wanted : I_S
$P = T \cdot I_S \;\Rightarrow I_S = P/T = 1000\text{ W}/573\text{ K} = 1.7\text{ Ct/s}$

4. Given: $T_A - T_B = 10\text{ K}$
$I_S = 500\text{ Ct/s}$
Wanted: P
$P = (T_A - T_B) \cdot I_S = 10\text{ K} \cdot 500\text{ Ct/s} = 5000\text{ W}$

5. (a) Given: $T_A - T_B = 25\text{ K}$
$I_S = 30\text{ Ct/s}$
Wanted: P
$P = (T_A - T_B) \cdot I_S = 25\text{ K} \cdot 30\text{ Ct/s} = 750\text{ W}$

(b) Given: $T = (273 + 25)\text{K} = 298\text{ K}$
$I_S = 30\text{ Ct/s}$
Wanted: P
$P = T \cdot I_S = 298\text{ K} \cdot 30\text{ Ct/s} = 8940\text{ W}$

Section 11.3

1. Given: $P = 20\text{ kW}$
$T_1 = (273 - 5)\text{K} = 368\text{ K}$
$T_2 = (273 + 20)\text{K} = 293\text{ K}$
Wanted: I_{S2}, I_{S1}, $I_{S\,\text{produced}}$
$P = T \cdot I_S \;\Rightarrow I_S = P/T$
(a) $I_{S2} = P/T_2 = 20\text{ kW}/293\text{ K} = 68.3\text{ Ct/s}$
(b) $I_{S1} = P/T_1 = 20\text{ kW}/268\text{ K} = 74.6\text{ Ct/s}$
(c) $I_{S\,\text{produced}} = I_{S1} - I_{S2} = (74.6 - 68.3)\text{ Ct/s} = 6.3\text{ Ct/s}$

2. Given: $P = 1000\text{ W}$
$T_1 = 373\text{ K}$
$T_2 = 1000\text{ K}$
Wanted: I_{S2}, I_{S1}, $I_{S1} - I_{S2}$
$P = T \cdot I_S \;\Rightarrow I_S = P/T$
(a) $I_{S2} = P/T_2 = 1000\text{ W}/1000\text{ K} = 1\text{ Ct/s}$
(b) $I_{S1} = P/T_1 = 1000\text{ W}/373\text{ K} = 2.7\text{ Ct/s}$
(c) $I_{S1} - I_{S2} = 1.7\text{ Ct/s}$

Section 11.5

1. Given: $\vartheta_A = 150\text{ °C}$
$\vartheta_B = 50\text{ °C}$
$I_S = 100\text{ Ct/s}$
Wanted: P
$T_A - T_B = 100\text{ K}$
$P = (T_A - T_B) \cdot I_S = 100\text{ K} \cdot 100\text{ Ct/s} = 10\text{ kW}$

2. Given: $P = 1000\text{ MW}$
$T_A = 750\text{ K}$ $\quad T_B = 310\text{ K}$
Wanted: I_S, P
$T_A - T_B = 750\text{ K} - 310\text{ K} = 440\text{ K}$
$P = (T_A - T_B) \cdot I_S \;\Rightarrow I_S = P/(T_A - T_B)$
$I_S = 1000\text{ MW}/440\text{ K} = 2.27\text{ MCt/s}$
$P_B = T_B \cdot I_S = 310\text{ K} \cdot 2.27\text{ MCt/s} = 704\text{ MW}$

3. A heat engine could be operated
- between the water of a cold mountain lake and the warmer water of a lake in the valley;
- between seawater at the equator and seawater at the North pole;
- between an iceberg that was towed to the equator, and warm seawater;
- between the Earth and outer space (space has a temperature of 2.7 K);
- between a volcano and seawater;
- between the surface water of an ocean and colder water at greater depth.

Section 11.6

1. Given: $P_{in} = 20\text{ kW}$
$P_{out} = 18\text{ kW}$
Wanted: V

$P_V = (20 - 18)\text{ kW} = 2\text{ kW}$
$V = (P_V/P_{in}) \cdot 100\,\% = (2\text{ kW}/20\text{ kW}) \cdot 100\,\% = 10\,\%$

2. Given: $V = 40\,\%$
$P_{in} = 10\text{ W}$
$T = 300\text{ K}$
Wanted: P_{out}, I_S

$V = (P_V/P_{in}) \cdot 100\,\%$
$\Rightarrow P_V = (V/100\,\%) \cdot P_{in} = (40/100) \cdot 10\text{ W} = 4\text{ W}$
$P_V = P_{in} - P_{out} = 10\text{ W} - 4\text{ W} = 6\text{ W}$
$I_{S\,\text{produced}} = P_V/T = 4\text{ W}/300\text{ K} = 0.013\text{ Ct/s}$

3. Given: $V = 8\,\%$
$P_{out} = 46\text{ kW}$
$T = 300\text{ K}$
Wanted: P_{in}, P_V, $I_{S\,\text{produced}}$
46 kW corresponds to 92 % of P_{in}.
$P_{in}/P_{out} = P_{in}/46\text{ kW} = 100\,\%/92\,\%$
$P_{in} = 46\text{ kW} \cdot (100/92) = 50\text{ kW}$
$P_V = P_{in} - P_{out} = (50 - 46)\text{ kW} = 4\text{ kW}$
$I_{S\,\text{produced}} = P_V/T = 4000\text{ W}/300\text{ K} = 13.3\text{ Ct/s}$

Section 11.7

1. Given: Fig. 11.20(a) and (c)
$\Delta S = 80\text{ Ct}$
Wanted: ΔT_{Cu}, ΔT_{Al}
From the figures:
$\Delta T_{Cu} = 70\text{ K}$ and $\Delta T_{Al} = 27\text{ K}$
Copper is getting warmer than aluminum.
$\Delta T_{Cu}/\Delta T_{Al} = 70\text{ K}/27\text{ K} \approx 2.6$

2. Given: Fig. 11.20 (e)
$\vartheta_1 = 20\text{ °C}$ $\quad \vartheta_2 = 100\text{ °C}$
$m = 100\text{ kg}$
Wanted: ΔS
From the figures:
$\Delta S = 1030\text{ Ct}$ for 1 kg
Therefore,
$\Delta S = 103\,000\text{ Ct} = 103\text{ kCt}$ for 100 kg

Section 11.8

1. Given: $m = 0.5\text{ kg}$
$P = 500\text{ W} = 500\text{ J/s}$
$\vartheta_1 = 25\text{ °C}$ $\quad \vartheta_2 = 100\text{ °C}$
Wanted: t
$\Delta E = cm\,\Delta T$
$P = \Delta E/t \;\Rightarrow t = \Delta E/P$
$\Rightarrow t = c \cdot m \cdot \Delta T/P$
$= 4180\text{ J/(kg} \cdot \text{K)} \cdot 0.5\text{ kg} \cdot 75\text{ K}/500\text{ (J/s)} = 313.5\text{ s} \approx 5\text{ min}$

2. Given: Water current = 0.1 kg/s
$t = 5\text{ min} = 300\text{ s}$
$\vartheta_1 = 15\text{ °C}$ $\quad \vartheta_2 = 45\text{ °C}$
Wanted: ΔE
$m = 0.1\text{kg/s} \cdot 300\text{ s} = 30\text{ kg}$
$\Delta E = cm\,\Delta T = 4180\text{ J/(kg} \cdot \text{K)} \cdot 30\text{ kg} \cdot 30\text{ K} = 3.76\text{ MJ}$

12. Phase transitions

Section 12.1

1. From Fig. 12.3, we get:

Entropy content at 100 °C

– 1 kg liquid water: 4600 Ct;
– 1 kg gaseous water: 10 700 Ct.

$f = 10700/4600 \approx 2.3$

Gaseous water (water vapor) contains 2.3 times as much entropy as liquid water.

2. Given: $m = 10$ kg
$\vartheta = 90$ °C

Fig. 11.20 (e) shows that we need about 115 Ct to change the temperature of water from 90 °C to 100 °C. To vaporize 1 kg of water, we need 6000 Ct.

Wanted: ΔS

$\Delta S = \Delta S_{warming} + \Delta S_{vaporization}$

$\Delta S_{warming} = 115 \cdot 10$ Ct = 1150 Ct

$\Delta S_{vaporization} = 10 \cdot 6000$ Ct = 60 000 Ct

$\Delta S = (1150 + 60\,000)$Ct = 61 150 Ct

3. Given: $\Delta S_{melting} = 6000$Ct

Wanted: m

To melt 1 kg ice we need 1200 Ct.
With 6000 Ct, (6000/1200)kg = 5 kg ice can be melted.

4. Given: Temperature change from 20 °C to 0 °C
Mass of soda = 0.25 kg

Wanted: Mass of melted ice

To cool 1 kg of water from 20°C to 0°C, 280 Ct have to be extracted (see Fig. 11.20(e) in the textbook). To cool 0.25 kg of water from 20°C to 0°C, (280/4) Ct = 70 Ct have to be extracted. The 70 Ct are used to melt ice. We need 1200 Ct to melt 1 kg of ice. 70 Ct melt 1 kg · (70/1200) = 58.3 g of ice.

5. Given: Temperature change from 15 ˚C to 60 ˚C
Mass of milk = 0.2 kg

Wanted: Mass of steam

Fig. 11.20(e) shows that we need about 620 Ct to warm 1 kg of water from 15°C to 60°C . For 0.2 kg, we need 620 · 0.2 Ct = 124 Ct. 1 kg of steam emits 6000 Ct when it condenses. Therefore, we need

1 kg · (124/6000) ≈ 20 g.

13. Gases

Section 13.1

1. A tire evens out the bumpiness of a street—such as from a small stone—because it is compressed. Since water is incompressible, a water filled tire could not counterbalance such unevenness.

2. At constant pressure, the air in the balloon expands, and a part of the air flows out of the balloon. The density of air in the balloon is therefore smaller than that of the surrounding air. The air in the balloon rises with the balloon.

Section 13.2

1. (a) Bubbles rise. Air escapes from the bottle. The cooled air was initially at ambient temperature. After sealing the bottle, entropy is added at V = const. According to (2a), the pressure will rise; it rises above ambient. When the bottle is opened, air escapes so that the pressure equilibrates.

(b) Water flows into the bottle. The heated air was at ambient temperature. As long as the bottle is sealed, entropy is withdrawn at V = const. According to (2b), the pressure drops, it drops below ambient. When the bottle is opened, water is pressed into it so that the pressure equilibrates.

2. The temperature rises in both gases. When V = const, the temperature rise is greater. The process at constant p can be performed in two steps. First, entropy is added at V = const. Temperature and pressure rise. This is what happened to the other gas. Then the gas is allowed to expand so that the pressure takes its previous value. According to (3b), the temperature decreases.

3. According to (2a), the temperature increases when entropy is added at V = const. According to (3b), the temperature goes down when the volume increases at S = const. Adding entropy and increasing the volume have opposite effects upon the temperature. If the volume increases sufficiently, it “wins” over adding entropy: the temperature decreases.

Section 13.3

1. Consider Fig. 13.10. During relaxation, the piston will hardly move. Energy will not be emitted. Moreover, the temperature of the liquid will not decrease. An almost equal amount of energy will leave the liquid together with the entropy after relaxation as was added with entropy before.

2. The mixture of fuel and air is compressed more strongly in a diesel engine. According to (2a), the temperature rises so strongly that the mixture ignites by itself.

3. At the end of the motion of the piston, the cylinder is still filled with steam at high pressure. When the valve is opened, the steam relaxes into the open. Since it could still give off a lot of energy, this energy is wasted.

Section 13.5

1. Water is heated in a pot on the stove. Entropy is added to the water through the bottom. It loses entropy through the side walls and at the water surface where it is needed for evaporation.

2. Because of their high temperature, the gases of the flame (mostly nitrogen of the air) have a lower density than the ambient air. They flow upwards and pull solid particles along.

14. Light

Section 14.3

a) The temperature is between T_A and T_B.

b) Energy flows from A to B and from B to A. The flow from A to B is stronger than the one from B to A. Energy flows from A to K and from K to A. The flow from A to K is stronger than the one from K to A. Energy flows from K to B and from B to K. The flow from K to B is stronger than the one from B to K.

Section 14.6

It is a parachute that is opened. The momentum current leaving the parachute depends upon its speed. Equivalently, the entropy current leaving the Earth depends upon its temperature.

The speed of the parachute adjusts so its momentum and its speed do not change any longer.

The temperature of the Earth adjusts so that its entropy and its temperature do not change any longer.

Both are processes of dynamic equilibrium.

15. Data and data carriers

Section 15.1

1. Receiving antenna - (electricity) - TV; piano - (sound) - ear; transmitting antenna - (electromagnetic waves) - receiving antenna.

2. Loudspeaker, siren, musical instrument.

3. Photo diode, video camera, camera

4. Infrared light = electromagnetic waves

5. Electricity - light; electromagnetic waves - sound.

6. Transmitting antenna, microphone.

7. (Electricity) - score board at a sports stadium - (light) - reporter - (sound) - microphone - (electricity) - transmitting antenna - (electromagnetic waves) - radio - (sound).

Section 15.3

1. $100\,000 \approx 65\,536 = 2^{16}$. A zip code carries about 16 bits.

2. A little more than 13 bits.

3. Almost 11 bits.

4. $2^5 = 32$ characters.

5. At the bottom, the tree has 27 ends, Fig. 15.1.

Since $2^4 = 16 < 27 < 32 = 2^5$, three characters carry between 4 and 5 bits.

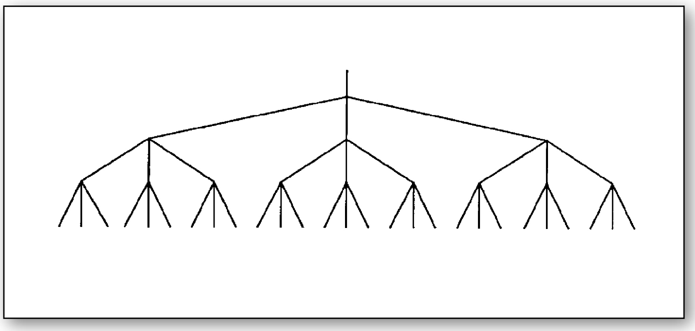

Fig. 15.1
See Section 15.3, Exercise **5**

6. A character from Source B has 1 bit more than a character from A.

7. To identify a card, the magician needs 4 bits. Each time a member of the audience points to a pile, the magician receives 2 bits. The magician places this pile second from the top. After this, the particular card is number 5, 6, 7, or 8. After the second round, it is the 6th card from the top.

Section 15.4

1. 180 keystrokes per minute = 3 characters per second;
$I_H = 3 \cdot 7$ bit/s = 21 bit/s.

2. $I_H = H/t \Rightarrow t = H/I_H = (40 \cdot 70 \cdot 7)$ bit/(2400 bit/s) ≈ 8 s

Section 15.5

1. Amount of data of a disk = 4 bits;
amount of data of a picture = $60 \cdot 80 \cdot 4$ bit = 19 200 bit

2. $18 \cdot 20$ bit = 360 bit

16. Electricity and electric currents

Section 16.3

1. I = 0.8 A. The current flows away from the junction.

2. I = 50 A. The current flows toward the junction.

3. The currents at P and Q must total a current of 3 A flowing to the right.

4. See Fig. 16.1

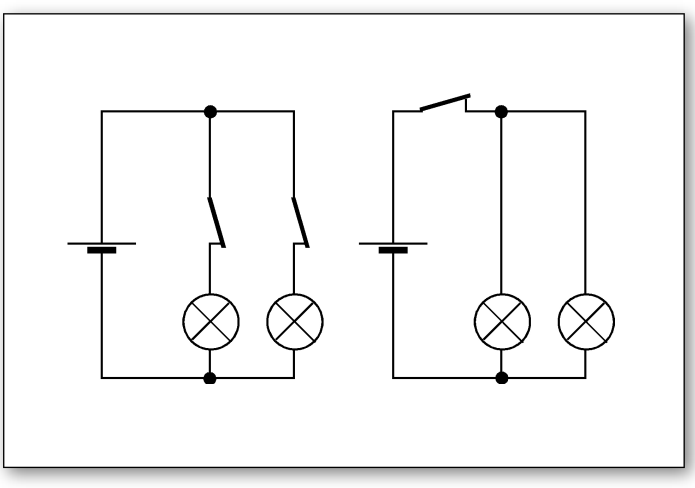

Fig. 16.1
See Section 16.3, Exercise **4**

5. All ammeters read 1.6 A.

6. The current at P is 11 A. See Fig. 16.2

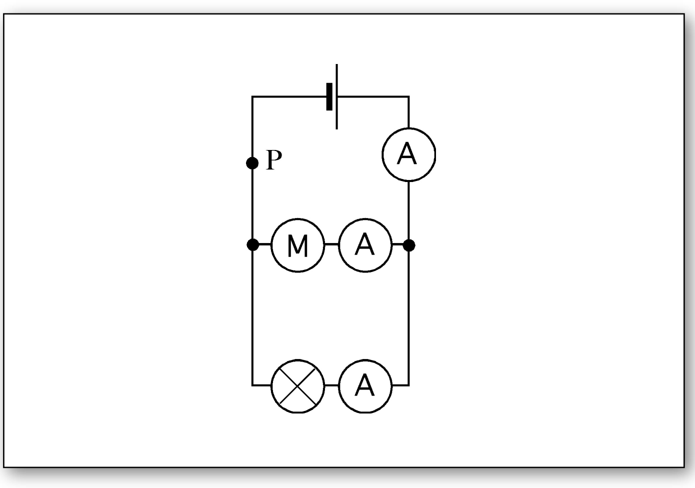

Fig. 16.2
See Section 16.3, Exercise **6**

Section 16.5

1. ϕ_1 = 4.5 V, ϕ_2 = 0 V, ϕ_3 = –4.5 V

2. ϕ_1 = 0 V, ϕ_2 = –12 V, ϕ_3 = 0 V

3. U_1 = 18 V, U_2 = 9 V, U_3 = 9 V

4. See Fig. 16.3

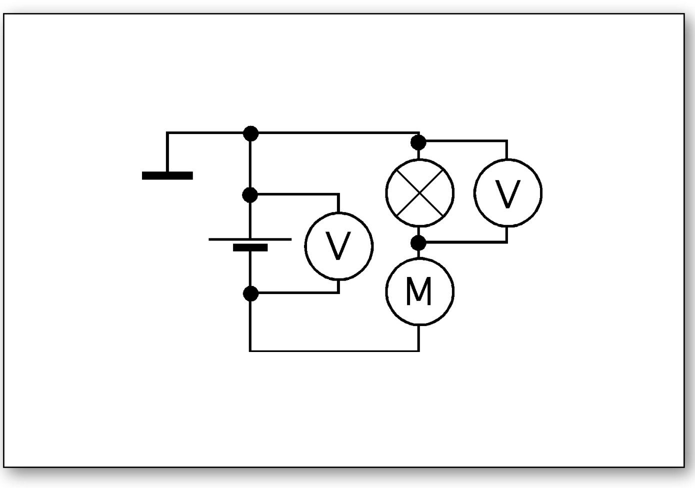

Fig. 16.3
See Section 16.5, Exercise **4**

5. Circuits in aircraft, rockets, satellites, cars, bicycles.

Section 16.7

1. The potentials are 0 V, 5 V and 9 V.

2. Left lamp: I = 1.6 A; right lamp: I = 0 A

3. ϕ_A = –20 V, ϕ_D = 40 V, $U_{Battery}$ = 60 V. With open switch, we have $\phi_A = \phi_B = \phi_C = \phi_D$ = 0 V.

4. (a) ϕ_P = 12 V, U_{L1} = 12 V, U_{L2} = 0 V

(b) ϕ_P = 6 V, U_{L1} = 6 V, U_{L2} = 6 V

The current through lamp L1 is stronger when the switch is closed (in this case the voltage across L1 is higher).

The current through L2 is stronger if the switch is open. If the switch is closed, the current is 0 A.

5. (a) ϕ_1 = 0 V, ϕ_2 = 150 V, $\phi_3 = \phi_4$ = 75 V
(b) $\phi_1 = \phi_4$ = 0 V, $\phi_2 = \phi_3$ = 150 V

If the switch is open, only the lamp on the right will shine.

6.(a) ϕ_1 = 0 V, $\phi_2 = \phi_3$ = 9 V, ϕ_4 = 18 V, ϕ_5 = 9 V
(b) ϕ_1 = 0 V, ϕ_2 = 9 V, ϕ_3 = –3 V, ϕ_4 = 6 V, ϕ_5 = 3 V.

Section 16.8

1. Given: U = 20 V
I = 4 mA
Wanted: R

$R = U/I$ = 20 V/4 mA = 5000 Ω = 5 kΩ

2. Given: R = 2 kΩ
U = 120 V
Wanted: I

$I = U/R$ = 120 V/2 kΩ = 60 mA

3. Given: R = 1 MΩ
I = 0.1 mA
Wanted: U

$U = R \cdot I$ = 1 MΩ · 0.1 mA = 100 V

4. Given: U = 35 V
I = 5 A
U_1 = 10 V
Wanted: R_1, U_2, R_2

$R_1 = U_1/I$ = 10 V/5 A = 2 Ω
$U_2 = U - U_1$ = 25 V
$R_2 = U_2/I$ = 25 V/5 A = 5 Ω

5. Given: U = 12 V
$R_1 = R_2 = R_3$ = 100 Ω
Wanted: U_1, U_2, U_3, I_1, I_2, I_3, I

U_3 = 12 V, $U_1 = U_2$ = 6 V
$I_1 = I_2$ = 6 V/100 Ω = 0.06 A
I_3 = 12 V/100 Ω = 0.12 A
$I = I_1 + I_3$ = 0.18 A

6. Left: Resistance 200 kΩ
Middle: Diode
Right: Resistance 5 Ω

7. Its resistance is 50 Ω. If n identical resistors are connected in parallel, the total resistance is 1/n of that of a single resistor.

8. Its resistance is 200 Ω. If n identical resistors are connected in series, the total resistance is n times that of a single resistor.

Section 16.11

1. The hair dryer is still wet. Water can established a conducting connection between the hand and the part at high potential.

2. If the worn part is the conductor at 0 V, nothing will happen. If it is the other terminal, there will be a short circuit.

17. Electricity and energy

Section 17.1

1. Given: $U = 12$ V
$I = 3.75$ A

Wanted: P

$P = U \cdot I = 12 \text{ V} \cdot 3.75 \text{ A} = 45 \text{ W}$

2. Given: $U = 12$ V
$P = 21$ W

Wanted: I

$P = U \cdot I \Rightarrow I = P/U = 21 \text{ W}/12 \text{ V} = 1.75 \text{ A}$

3. Given: $I = 2.4$ A
$U_1 = 2$ V
$U_2 = 6$ V

Wanted: P_{total}, P_1, P_2

$P_{total} = (2 \text{ V} + 6 \text{ V}) \cdot 2.4 \text{ A} = 19.2 \text{ W}$

$P_1 = 2 \text{ V} \cdot 2.4 \text{ A} = 4.8 \text{ W}$

$P_2 = 6 \text{ V} \cdot 2.4 \text{ A} = 14.4 \text{ W}$

4. Given: $U = 12$ V
$I_1 = 2$ A
$I_2 = 3$ A

Wanted: P_{total}, P_1, P_2

$P_{total} = 12 \text{ V} \cdot (2 \text{ A} + 3 \text{ A}) = 60 \text{ W}$

$P_1 = 12 \text{ V} \cdot 2 \text{ A} = 24 \text{ W}$

$P_2 = 12 \text{ V} \cdot 3 \text{ A} = 36 \text{ W}$

5. Given: $U_1 = 12$ V
$U_2 = 9$ V
$I = 1.5$ A

Wanted: P_{Motor}, P_1, P_2

$U_{Motor} = U_1 + U_2 = 21 \text{ V}$

$P_{Motor} = 21 \text{ V} \cdot 1.5 \text{ A} = 31.5 \text{ W}$

$P_1 = 12 \text{ V} \cdot 1.5 \text{ A} = 18 \text{ W}$

$P_2 = 9 \text{ V} \cdot 1.5 \text{ A} = 13.5 \text{ W}$

6. $U_{AB} = 3$ V

The upper cell will be discharged twice as fast as the lower ones.

Combined source:

$P = 3 \text{ V} \cdot 10 \text{ mA} = 30 \text{ mW}$

Upper monocell:

$P = 1.5 \text{ V} \cdot 10 \text{ mA} = 15 \text{ mW}$

Each of the lower monocells:

$P = 1.5 \text{ V} \cdot 5 \text{ mA} = 7.5 \text{ mW}$

7. Given: $I = 60$ mA
$E = 20$ kJ

Wanted: P, t

$U = 3 \cdot 1.5 \text{ V} = 4.5 \text{ V}$

$P = U \cdot I = 4.5 \text{ V} \cdot 60 \text{ mA} = 0.27 \text{ W}$

$t = E/P = 3 \cdot 20 \text{ kJ}/0.27 \text{ W} \approx 222\,000 \text{ s} \approx 62 \text{ h}$

9. Given: $U = 80$ V
$R = 2$ kΩ

Wanted: I, P

$I = U/R = 80 \text{ V}/2 \text{ k}\Omega = 40 \text{ mA}$

$P = U \cdot I = 80 \text{ V} \cdot 40 \text{ mA} = 3.2 \text{ W}$

10. Given: $R = 2\ \Omega$
$I_R = 10$ A
$P_L = 100$ W

Wanted: U, I_L, I

$U = R \cdot I_R = 2\ \Omega \cdot 10 \text{ A} = 20 \text{ V}$

$I_L = P_L/U = 100 \text{ W}/20 \text{ V} = 5 \text{ A}$

$I = I_R + I_L = 10 \text{ A} + 5 \text{ A} = 15 \text{ A}$

Section 17.2

1. Given: $U_Q = 200$ V
$R_L = 2 \cdot 0.5\ \Omega = 1\ \Omega$
$I = 8$ A

Wanted: P_Q, P_L, P_M

$P_Q = U_Q \cdot I = 200 \text{ V} \cdot 8 \text{ A} = 1600 \text{ W}$

$U_L = R_L \cdot I = 1\ \Omega \cdot 8 \text{ A} = 8 \text{ V}$

$P_L = U_L \cdot I = 8 \text{ V} \cdot 8 \text{ A} = 64 \text{ W}$

$P_M = P_Q - P_L = 1600 \text{ W} - 64 \text{ W} = 1536 \text{ W}$

2. Given: I, U_{Lamp}, R_{Cable}

Wanted: U_{Cable}, $U_{Power\ supply}$, P_{Cable}

(a) $U_{Cable} = R_{Cable} \cdot I = 1\ \Omega \cdot 5 \text{ A} = 5 \text{ V}$

$U_{Power\ supply} = 12 \text{ V} + 2 \cdot 5 \text{ V} = 22 \text{ V}$

$P_{Cable} = U_{Cable} \cdot I = 10 \text{ V} \cdot 5 \text{ A} = 50 \text{ W}$

(b) $U_{Cable} = 1\ \Omega \cdot 2.5 \text{ A} = 2.5 \text{ V}$

$U_{Power\ supply} = 24 \text{ V} + 2 \cdot 2.5 \text{ V} = 29 \text{ V}$

$P_{Cable} = U_{Cable} \cdot I = 5 \text{ V} \cdot 2.5 \text{ A} = 12.5 \text{ W}$

The higher the voltage applied for an energy transport, the lower the losses in the cables.

18. The magnetic field

Section 18.1

Take a third magnet and bring it close to all the poles of the other two magnets. It is found that the other magnets behave identically.

Section 18.3

1. See Fig. 18.1

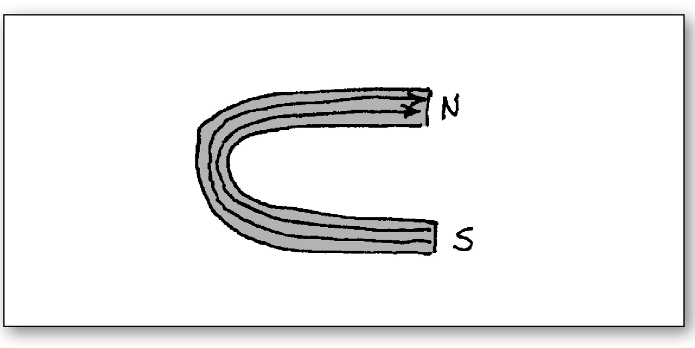

Fig. 18.1
See Exercise **1.**, Section 18.3

2. See Fig. 18.2a
3. See Fig. 18.2b

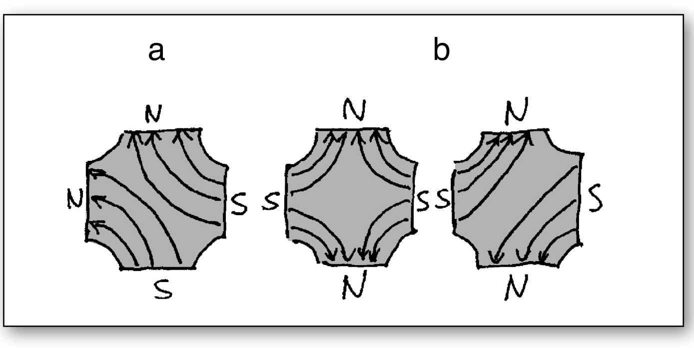

Fig. 18.2
See Exercises **2.** and **3.**, Section 18.3

4. See Fig. 18.3

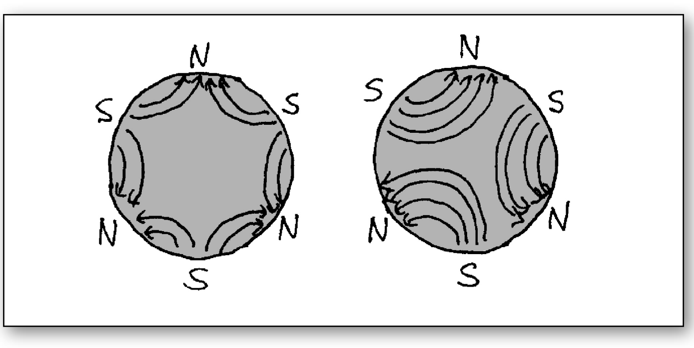

Fig. 18.3
See Exercise **4.**, Section 18.3

5. The ring has to be broken. If there are magnetic poles at the break, the ring must have been magnetized.

Section 18.6

See Fig. 18.4

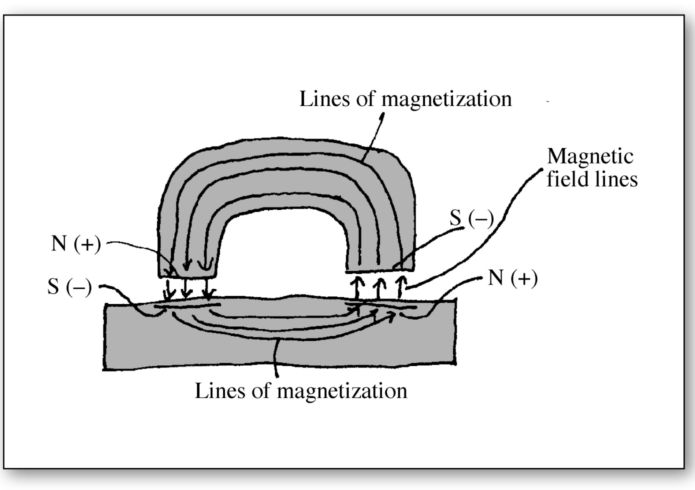

Fig. 18.4
See Section 18.6

Section 18.7

See Fig. 18.5

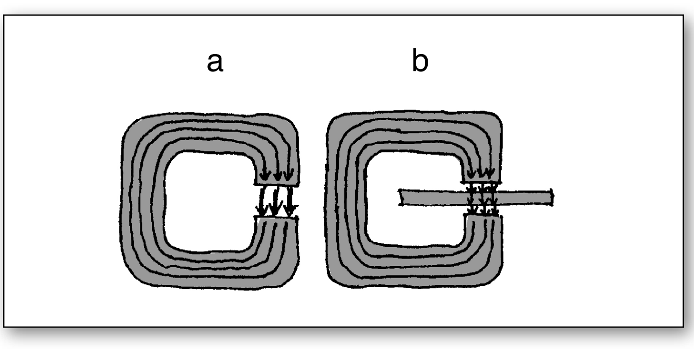

Fig. 18.5
See Section 18.7

Section 18.9

1. Two parallel wires are made into a coil. On one side, the ends of the wires are connected. The other ends are connected to a power supply so that the current in the wires flows in opposite directions. The effect of one of the wires is compensated by the effect of the other.

2. Neighboring turns are attracted by the field. The field pushes the parts of a wire of a single loop outward.

Section 18.10

1. Track switch of toy trains or of trams, magnet used at a junk yard.

2. Similar to a standard direct current bell, but without interrupter.

3. The permanent magnet basically oscillates back and forth, but it is too inert to do so. If we use a piece of soft iron instead, we have an alternating current ammeter.

Section 18.11

1. The motor does not start by itself. It can operate only at a particular rotational frequency: 50 revolutions per second.

2. The stationary magnets are electromagnets. They are permanently connected to the power supply, i.e., poles are not switched constantly. The rotor is the same as in Fig. 18.47.

Section 18.12

1. The pieces of iron form magnetic poles because of the magnetic field of the Earth. This changes the field of the Earth.

2. They will orient themselves in parallel. Their common direction does not have to be North-South.

Section 18.13

1. The magnet must be moved fast; the magnet should be strong (strong magnetic charge); the solenoid has to have many turns.

2. A short voltage surge of a particular sign, followed by a surge of the opposite sign.

Section 18.15

1. Given: Windings: 1000 and 5000
$U_1 = 220$ V

Wanted: U_2

$U_1 / U_2 = n_1 / n_2 \Rightarrow U_2 = (n_2/n_1)\, U_1$

Using $n_2/n_1 = 5000/1000 = 5$

we have $U_2 = 1100$ V.

Using $n_2/n_1 = 1000/5000 = 0.2$

we have $U_2 = 44$ V.

2. Given: $U_1 = 220$ V
$U_2 = 11$ V
$I_2 = 2$ A

Wanted: n_1/n_2
I_1

$n_1/n_2 = U_1/U_2 = 220 \text{ V}/11 \text{ V} = 20$

The number of turns of the secondary solenoid equals 1/20 that of the primary solenoid.

$U_1 \cdot I_1 = U_2 \cdot I_2 \;\Rightarrow\; I_1 = U_2 \cdot I_2/U_1 = 11 \text{ V} \cdot 2 \text{ A}/220 \text{ V} = 0.1 \text{ A}$

3. Given: $n_1 = 1000$
$n_2 = 10\,000$
$U_1 = 220$ V
$I_1 = 0.1$ A

Wanted: U_2, I_2

$U_2 = (n_2 / n_1)\, U_1 = (10\,000/1000) \cdot 220 \text{ V} = 2200 \text{ V}$

$I_2 = U_1\, I_1 / U_2 = 220 \text{ V} \cdot 0.1 \text{ A}/2200 \text{ V} = 0.01 \text{ A} = 10 \text{ mA}$

4. The cables of the feed line have to be very thick to accept 10,000 A without getting hot. The return line must be very well insulated to take 10,000 V without spark-over. It is cheaper to insulate lines well than to use thick cables (transmission tower).

19. Electrostatics

Section 19.2

1. The electric current flows to the right. It is equal to
0.5 A + 0.3 A = 0.8 A.

2. $2\ \text{C}/(1.6 \cdot 10^{-19}\ \text{C}) = 1.25 \cdot 10^{19}$

Section 19.4

1. Upon touching A, negative charge carriers flow from B to A. B will obtain a positive net charge. Now, both spheres are positively charged, the field will lead to repulsion.

2. Attraction and repulsion are observed also when the objects are made from non-magnetizable materials (such as aluminum).

3. When A touches B, it is charged with electricity from B. Now, sphere A is repelled by B so that it touches C. First, A discharges, then it is charged with electricity from C. Now the field pushes A back toward B. Therefore, sphere A oscillates between B and C.

Section 19.6

1. Given: $I = 0.002$ A
$U = 240$ V
$t = 120$ s

Wanted: Q, C

$Q = I \cdot t = 2\ \text{mA} \cdot 120\ \text{s} = 240\ \text{mC}$

$C = Q/U = 240\ \text{mC}/240\ \text{V} = 1\ \text{mF}$

2. Given: $C = 0.000\,08$ F
$U = 150$ V

Wanted: Q

$Q = C \cdot U = 0.000\,08\ \text{F} \cdot 150\ \text{V} = 0.009\ \text{C}$

Section 19.7

1. Given: $U = 20\,000$ V
$I = 0.0002$ A

Wanted: P

$P = U \cdot I = 20\,000\ \text{V} \cdot 0.000\,2\ \text{A} = 4\ \text{W}$

2. The color dots of the screen are labeled r, g, and b (red, green, blue).

Color impression	Luminescent Points
red	r
green	g
blue	b
yellow	r, g
turquoise	g, b
orange	r, g (weak)
black	-
white	r, g, b
brown	r (weak), g (weak)

20. Data systems technology

Section 20.1

1. Record player - loudspeaker; TV camera - transmitting antenna; microphone - ear; telephone call.

2. Repeating loud what was whispered to him.

Section 20.2

1. We cannot infer uniquely from the number shown to the number entered; for example: $9 = 3^2$ and $9 = (-3)^2$.

2. No, since we can infer x from the value of x^3.

Section 20.3

1. The first question might be: “Is it an even number?” or “Is the number smaller than four?”. The answer to the question “Is it the number six?”, gives Lilly less than 1 bit since one answer (“no”) is more probable than the other one (“yes”).

2. The minimal number of Yes-No questions is 5 since the person receives a total of 5 bits.

3. We assume that A can choose one term out of 30,000 (roughly the number of nouns in a dictionary). Since $30\,000 \approx 2^{15}$, B needs 15 Yes-No questions in an optimal strategy. So that the answers are equally probable, B should not start with a question such as “Is it a pencil?” but rather “Is it alive?” or “Can it be seen from here?”

21. Light

Section 21.3

1. A small fraction of the light will be reflected. This gives the apple its shine. Of the rest, all but the red light will be absorbed. Red light is diffusely reflected.

2. All light except for green light is absorbed. Green light is partly transmitted and scattered, partly diffusely reflected.

3. The pullover absorbs all types of light except for red light. It also absorbs the blue light of the fluorescent tube.

4. Almost all the light is reflected. A small part is transmitted without scattering.

5. The light is either transmitted or absorbed. Depending upon the location on the slide, different types of light are absorbed.

6. The light is either absorbed or diffusely reflected. Which light is absorbed depends upon the location on the postcard.

7. Light will be immediately absorbed by the inside surface of the sacks.

Section 21.4

1. Light of all types comes from all directions.

2. Light of all types comes from two perpendicular directions.

3. Light of a single direction and a single color.

Section 21.5

1. See Fig. 21.1

2. See Fig. 21.1

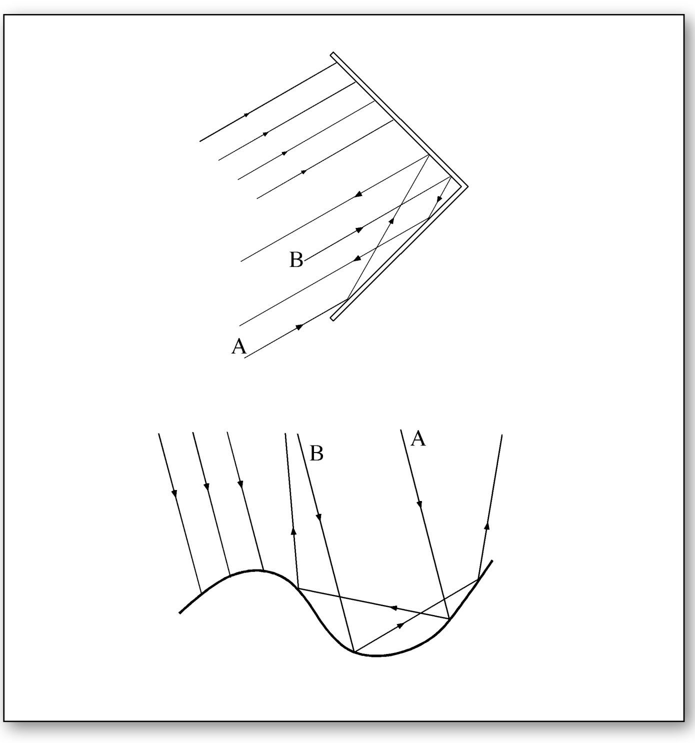

Fig. 21.1
See Section 21.5, Exercises **1** and **2**

Section 21.6

See Fig. 21.2

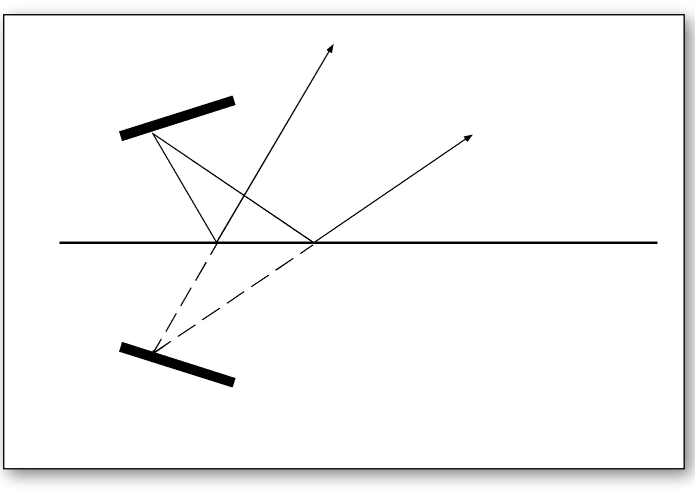

Fig. 21.2
See Section 21.6

Section 21.7

See Fig. 21.3

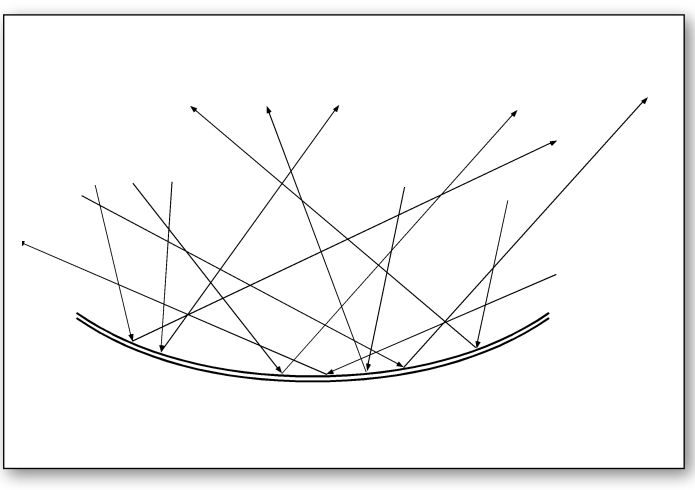

Fig. 21.3
See Section 21.7

Section 21.8

1. See Fig. 21.4

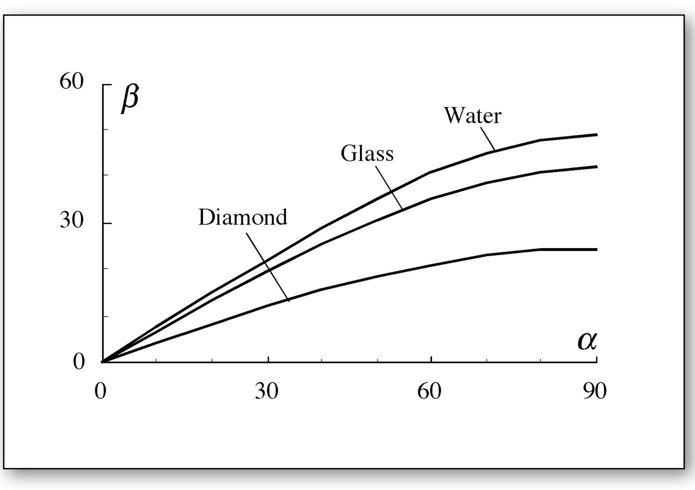

Fig. 21.4
See Section 21.8, Exercise **1**

2. See Fig. 21.5

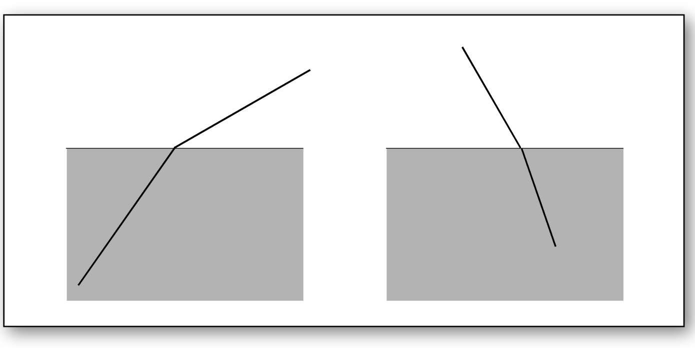

Fig. 21.5
See Section 21.8, Exercise **2**

Section 21.9

1. See Fig. 21.6

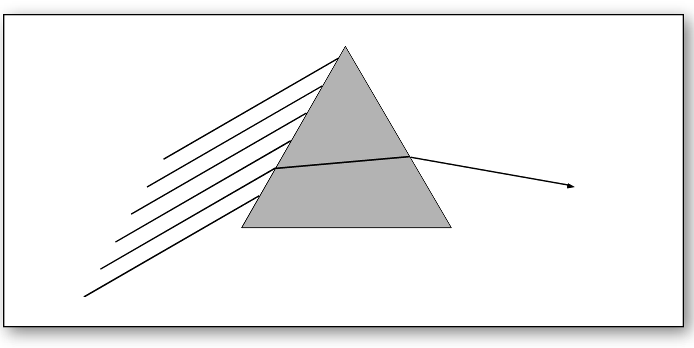

Fig. 21.6
See Section 21.9, Exercise **1**

2. See Fig. 21.7

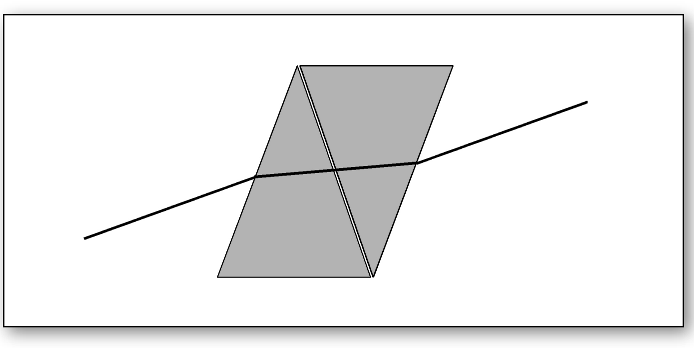

Fig. 21.7
See Section 21.9, Exercise **2**

Section 21.10

1. See Fig. 21.8

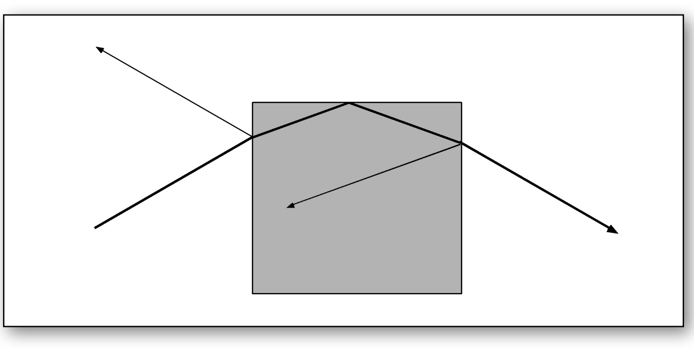

Fig. 21.8
See Section 21.10, Exercise **1**

2. See Fig. 21.9

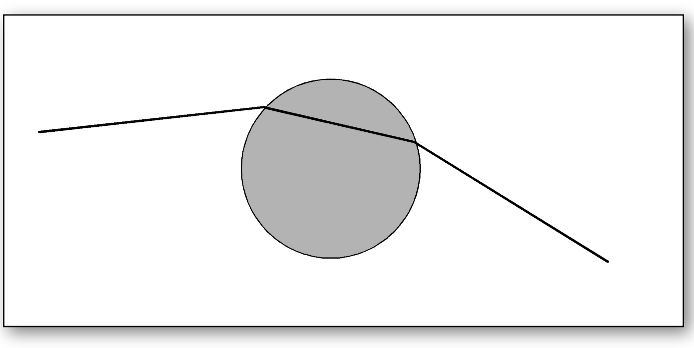

Fig. 21.9
See Section 21.10, Exercise **2**

22. Optical image formation

Section 22.1

1. The image on the slide is difficult to see since the incident light is not scattered. To view the slide one holds it up to a background that is evenly bright such as the sky or a well lit piece of paper.

2. The light from the projector is reflected by a mirror at every point only in a single direction. One would see the back of the room with the projector.

Section 22.2

1. The light is not scattered into our eyes.

2. One does not see anything. The light from the point source will be reflected and will hit the wall of the camera obscura at some point.

Section 22.3

1. Given: $g = 100$ m
$b = 16$ cm
$B = 8$ cm

Wanted: G

$G = Bg/b = 50$ m

2. Given: $G = 157$ m
$b = 20$ cm
$B = 2$ cm

Wanted: g

$g = Gb/B = 1570$ m

3. 4 m high

Section 22.4

See Fig. 22.1. By combining the mirrors we obtain a concave mirror.

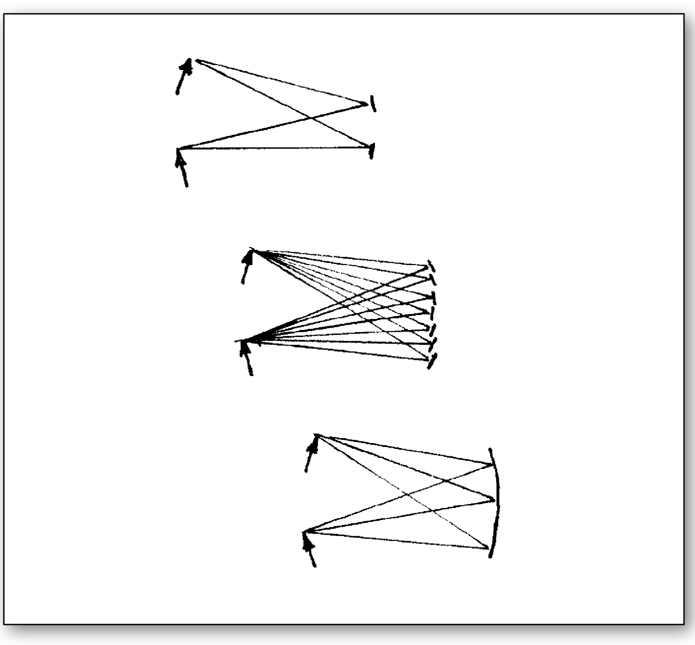

Fig. 22.1
See Section 22.4

Section 22.6

We produce an image of the flame of the candle with the help of the lens. The candle is placed far from the lens. As a result, the image distance equals the focal length.

A part of the light of the candle is made into parallel rays. The distance between candle and lens then equals the focal length.

Section 22.8

1. –1 dpt

2. For a lens we have

$D = 1/f = 1/(0.4\text{m}) = 2.5$ dpt

The refractive power of the lenses combined is 5 dpt. Therefore, the focal length of the system of lenses is $f = 1/(5\text{dpt}) = 0.2$ m.

3. $D_1 = 1/(0.2\text{m}) = 5$ dpt, $D_2 = 1/(0.5\text{m}) = 2$ dpt, $D_3 = -2$ dpt.

$D = D_1 + D_2 + D_3 = 5$ dpt

4. The lens is combined with an auxiliary lens having positive refractive power so that we have a system with positive refractive power. The focal length, i.e., the refractive power, of the system is measured. From this we subtract the refractive power of the auxiliary lense to obtain the wanted refractive power.

Section 22.11

1. Short exposure when it is light, long exposure when it is dark.

2. Small aperture: large focal range; this is possible only if it is bright enough; large aperture: small focal range; it need not be very bright.

3. If the aperture is large, the focal range is small. One has to be more careful in setting focus.

5. A wide angle lens. As seen from the photographer, the party guests are spread over a large angle.

6. A tele-photo lens. One moves away from the person until she appears as large again as before with the normal lens. Now, the mountains have become bigger by the ratio of the focal lengths of the two lenses.

7. An object that covers the entire image area on the film of the 35 mm camera will equally cover the entire area of film of a pocket camera.

8. Given: $G = 10$ m
$g = 200$ m
$b = 50$ mm (180 mm)

Wanted: B

Normal lens: $B = 2.5$ mm

Tele-photo lens: $B = 9$ mm

Section 22.13

1. The lenses of the glasses of a near sighted person are thinner in the middle than at the edge. Those of the far sighted person are thicker in the middle.

2. This only works with the glasses of a far sighted person.

3. The spot has the form of a disk. It is the image of the Sun.

Section 22.14

1. All the light passing through the slide is already passed through the lens with the help of the condenser.

2. If the lens is bigger, more of the light scattered back by the image will be used to form an image on the screen.

3. The object distance is almost equal to the focal length. With

$b = 5$ m, $B = 2.40$ m, $G = 24$ mm

we have $g = f = 50$ mm

Section 22.15

1. Flickering vertical stripes.

2. The beam is interrupted 48 times per second (rather than 24 times). The film is transported only during every second interruption.

Section 22.18

1. The antenna is oriented so that we get the best reception. The orientation of the antenna tells us the direction in which we find the satellite.

2. The diameter of the telescope is 750 times that of the pupil of the eye. The area is $750^2 = 562\,500$ times as large. The telescope collects 562 500 times as much light as the eye.

23. Colors

Section 23.1

1. We might use a cube. Three perpendicular edges form the coordinate axes for color tone, saturation, and brightness.

2. The scale of color tone has neither a beginning nor an end, it is closed. The saturation scale has both a beginning and an end. The brightness scale has a beginning (total darkness) but no end because, in principle, the brightness of light can be increased indefinitely.

3. The angle.

4.

	Color tone	Brightness	Saturation
Bread roll	yellow-orange	high	medium
Powdered cocoa	red-orange	low	strong
Hot chocolate	red-orange	high	weak
Cola	orange	very low	medium
Artichoke	turquoise	high	weak
Skin	red-orange	high	weak
Zinc rain gutter	blue	medium	very weak
Rust	red	low	medium
InterCity train	magenta	high	strong
Regional train	blue	high	medium-strong
Local train	green	high	medium-strong

Section 23.3

1.

	Red	Yellow-green	Blue
Yellow	bright	bright	dark
Violet	bright	dark	bright
Pink	bright	medium	medium
Olive	dark	medium	dark
Ocher	bright	bright	medium
Dark gray	medium	medium	medium

2. Completely saturated colors at the edge of the color circle cannot be produced (except for the three pure pixel colors).

Section 23.4

	Orange	Turquoise	Purple
Red	bright	dark	bright
Blue	dark	bright	bright
Pink	bright	medium	bright
White	bright	bright	bright
Brown	medium	dark	dark
Black	dark	dark	dark

Section 23.6

1. See Fig. 23.1

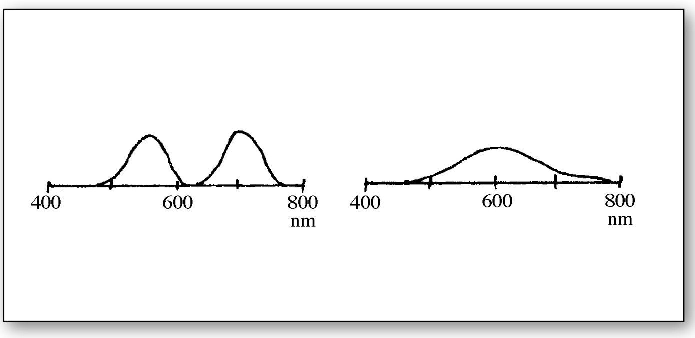

Fig. 23.1
See Section 23.6, Exercise **1**

2. See Fig. 23.2

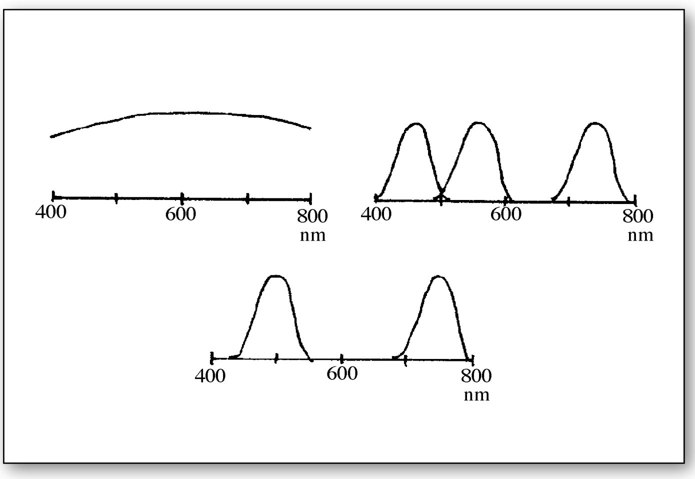

Fig. 23.2
See Section 23.6, Exercise **2**

24. Rate of reaction and chemical potential

Section 24.1

1.
H_2O: m/n = 18.01494 g/mol ≈ 0.018 kg/mol
O_2: m/n = 31.998 g/mol ≈ 0.032 kg/mol
CO_2: m/n = 44.009 g/mol ≈ 0.044 kg/mol
Ag_2S: m/n = 247.804 g/mol ≈ 0.248 kg/mol
$Pb(NO_3)_2$: m/n = 331.198 g/mol ≈ 0.331 kg/mol
$C_{12}H_{22}O_{11}$: m/n = 342.296 g/mol ≈ 0.342 kg/mol

2. m/n = 0.342 kg/mol

$$n = \frac{m}{0.342 \text{ kg/mol}} = \frac{0.1 \text{ kg}}{0.342 \text{ kg}} \cdot \text{mol}$$

n = 0.29 mol

3. 1 l water weighs 1 kg.
m/n = 0.018 kg/mol

$$n = \frac{1 \text{ kg}}{0.018 \text{ kg}} \cdot \text{mol} = 55.5 \text{ mol}$$

4. For propane we have m/n = 0.044 kg/mol

$$n = \frac{m}{0.044 \text{ kg/mol}} = \frac{12 \text{ kg}}{0.044 \text{ kg}} \cdot \text{mol} = 273 \text{ mol}$$

Section 24.2

1. $4Fe + 3O_2 \rightarrow 2Fe_2O_3$
8 mol Fe + 6 mol O_2 → 4 mol Fe_2O_3

2. (a) For C we have m/n = 12.011 g/mol.

$$n = \frac{m}{12 \text{ g/mol}} = \frac{4 \text{ g}}{12 \text{ g}} \cdot \text{mol} = (1/3)\text{mol}$$

(1/3)mol CO_2 + (2/3)mol Mg → (1/3)mol C + (2/3)mol MgO

(b) CO_2: m/n = 44 g/mol
$m = n$ · 44 g/mol = (1/3)mol · 44 g/mol = 14.7 g

Mg: m/n = 24.3 g/mol
$m = n$ · 24.3 g/mol = (2/3)mol · 24.3 g/mol
= 16.2 g

(c) CO_2: n = (1/3)mol
Number of molecules: (1/3) · 6.022 · 10^{23} = 2.0 · 10^{23}

(d) 1 mol CO_2 + 2 mol Mg → 1 mol C + 2 mol MgO

corresponds to a conversion of 1 mol. In our case, 1/3 of this is converted.
→ n(R) = 1/3 mol

3. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
→ If 2 mol of water are produced per second, the reaction rate is 1 mol/s. In our case, 1/20th of this is produced. → $I_{n(R)}$ = 0.05 mol/s

4. After a distance of 100 km, 10 l of water have been produced. Since the speed is 50 km/h, and 1 l water weighs 1 kg, 10 kg of water are produced in 2h:

t = 2 h = 7200 s
m = 10 kg

Since m/n = 0.018 kg/mol, we have

$$n = \frac{10 \text{ kg}}{0.018 \text{ kg}} \cdot \text{mol} = 555.56 \text{ mol}$$

$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

18 mol of water corresponds to a conversion of 1 mol.

$$n(\text{R}) = \frac{555.56}{18} \text{mol} = 30.86 \text{ mol}$$

$$I_{n(\text{R})} = \frac{n(\text{R})}{t} = \frac{30.86 \text{ mol}}{7200 \text{ s}} = 0.00429 \text{ mol/s}$$

Section 24.3

1. Substances on the left: A, substances on the right: B.
(a) μ(A) – μ(B) = 1138 kG
(b) μ(A) – μ(B) = 117 kG
(c) μ(A) – μ(B) = 3385.65 kG
(d) μ(A) – μ(B) = –5797.78 kG
(e) μ(A) – μ(B) = 188.62 kG

The reactions a, b, c and e are possible, reaction d is not.

2.
CuO + Zn → Cu + ZnO
μ(A) – μ(B) = 188.62 kG
CuO +Mg → Cu + MgO
μ(A) – μ(B) = 439.26 kG
CuO + Fe → Cu + FeO
μ(A) – μ(B) = 115.44 kG

3.
I_2(solid) → I_2(w. sol.)
μ(A) – μ(B) = –16.40 kG
KOH → K^+ + OH^-
μ(A) – μ(B) = 61.5 kG
NH_4Cl → NH_4^+ + Cl^-
μ(A) – μ(B) = 7.44 kG
NH_3(gas) → NH_3(w. sol.)
μ(A) – μ(B) = 10.09 kG
AgCl → Ag^+ + Cl^-
μ(A) – μ(B) = –55.66 kG

A 1M solution can only be produced of KOH, NH_4Cl and NH_3.

Section 24.5

3. The reaction is inhibited. If not, the explosives would explode by themselves. They could not be stored.

25. Amount of substance and energy

Section 25.2

1. $2NaCl \leftrightarrow 2Na + Cl_2$

For sodium we have

$m/n = 0.023$ kg/mol

$$n = \frac{1\ \text{kg}}{0.023\ \text{kg}} \text{mol} = 43.5\ \text{mol}$$

$\mu(A) - \mu(B) = 384$ kG

$E = (\mu(A) - \mu(B)) \cdot n = 384$ kG · 43.5 mol = 16 700 kJ = 16.7 MJ

2. $Pb + Cl_2 \rightarrow PbCl_2$

$n = 2$ mol

$\mu(A) - \mu(B) = 314$ kG

$E = 2$ mol · 314 kG = 628 kJ

Section 25.3

1. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$$\mu(A) - \mu(B) = 818\ \text{kG}$$

$P = (\mu(A) - \mu(B)) \cdot I_{n(R)} = 818$ kG · 1 mol/s = 818 kJ/s = 818 kW

2. $\mu(A) - \mu(B) = 394$ kG

(a) $P = (\mu(A) - \mu(B)) \cdot I_{n(R)} \rightarrow$

$I_{n(R)} = P/(\mu(A) - \mu(B)) = 100$W/394 kG = 0.00025 mol/s

(b) For $PbSO_4$ we have $m/n = 303.25$ g/mol.

$$n = \frac{2000\ \text{g}}{303.25\ \text{g}} \text{mol} = 6.6\ \text{mol}$$

$n(R) = n/2 = 3.3$ mol

$E = (\mu(A) - \mu(B)) \cdot n(R) = 394$ kG · 3.3 mol = 1300 kJ

26. Heat balance of reactions

Section 26.1

1. $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

For octane we have *m/n* = 114.2 g/mol.

$$n = \frac{1000\ \text{g}}{114.2\ \text{g}}\text{mol} = 8.76\ \text{mol}$$

n(R) = *n*/2 = 4.38 mol
μ(A) – μ(B) = 10592 kG

$$S_{\text{produced}} = \frac{10592\ \text{kG}}{298\ \text{K}} \cdot 4.38\ \text{mol} = 156\ \text{kCt}$$

2. $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

For iron we have *m/n* = 55.847 g/mol.

$$n = \frac{1000\ \text{g}}{55.847\ \text{g}}\text{mol} = 17.9\ \text{mol}$$

n(R) = *n*/4 = 4.48 mol
μ(A) – μ(B) = 2 · 742.24 kG = 1484.48 Ct

$$S_{\text{produced}} = \frac{1484.48\ \text{kG}}{298\ \text{K}} \cdot 4.48\ \text{mol} = 22.3\ \text{kCt}$$

Section 26.2

1. $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Consider a conversion of 1 mol.
μ(A) – μ(B) = 1484.48 kG

$$S_{\text{produced}} = \frac{1484.48\ \text{kG}}{298\ \text{K}} \cdot 1\ \text{mol} = 4980\ \text{Ct}$$

S(A) – *S*(B) = 549.41 Ct
S(A) – *S*(B) + S_{produced} = 549 Ct + 4980 Ct = 5529 Ct

5529 Ct will be emitted.

2. $CaCl_2 \rightarrow Ca^{++} + 2Cl^-$
μ(A) – μ(B) = 65.37 kG

$$S_{\text{produced}} = \frac{65.37\ \text{kG}}{298\ \text{K}} \cdot 1\text{mol} = 219.36\ \text{Ct}$$

S(A) – *S*(B) = 56.07 Ct
S(A) – *S*(B) + S_{produced} = 275.43 Ct

275.43 Ct per mol are left. The solution will get warmer.

3. $NaBr \rightarrow Na^+ + Br^-$
μ(A) – μ(B) = 16.6 kG

$$S_{\text{produced}} = \frac{16.6\ \text{kG}}{298\ \text{K}} \cdot 1\ \text{mol} = 55.7\ \text{Ct}$$

S(A) – *S*(B) = 99.71 Ct
S(A) – *S*(B) + S_{produced} = 155.4 Ct

155.4 Ct per mol are left. The solution will get warmer.

4. $KNO_3 \rightarrow K^+ + NO_3^-$
μ(A) – μ(B) = 1.47 kG

$$S_{\text{produced}} = \frac{1.47\ \text{kG}}{298\ \text{K}} \cdot 1\ \text{mol} = 4.93\ \text{Ct}$$

S(A) – *S*(B) = –116.02 Ct
S(A) – *S*(B) + S_{produced} = –111.09 Ct

111.09 Ct are missing to maintain the standard temperature. The solution will get cold.

27. Relativity

Section 27.2

1. E = 500 kJ

$$m = \frac{E}{k} = \frac{500\ \text{kJ}}{9 \cdot 10^{16}\ \text{J/kg}} \approx 5.6 \cdot 10^{-12}\,\text{kg}$$

A car takes about 10 l/100 km, i.e., about 10 kg/100 km. For v = 100 km/h it takes 10 kg/h or

10 kg/h = 10 kg/3600 s ≈ 3 · 10^{-3} kg/s.

The acceleration phase lasts for about 10 s. The car will be lighter by

3 · 10^{-3} kg/s · 10 s = 3 · 10^{-2} kg

This decrease is about 5 · 10^{9} times larger than the increase calculated before.

2. 1000 J fall on a square meter every second:

$$m = \frac{E}{k} = \frac{1000\ \text{J}}{9 \cdot 10^{16}\ \text{J/kg}} \approx 1.1 \cdot 10^{-14}\,\text{kg}$$

Therefore,

$$\frac{m}{t} = 1.1 \cdot 10^{-14}\,\text{kg/s}$$

Therefore,

$$t = \frac{m}{1.1 \cdot 10^{-14}\,\text{kg/s}} = \frac{0.001\,\text{kg}}{1.1 \cdot 10^{-14}\,\text{kg/s}} = 0.9 \cdot 10^{11}\,\text{s}$$

$$= 9000 \cdot 10^{7}\,\text{s} = 25 \cdot 10^{6}\,\text{h} \approx 10^{6}\,\text{d} \approx 2700\ \text{years}$$

3.

$$m = \frac{E}{k} = \frac{3.8 \cdot 10^{26}\,\text{J}}{9 \cdot 10^{16}\,\text{J/kg}} \approx 4.2 \cdot 10^{9}\,\text{kg}$$

The Sun loses 4.2 · 10^{9} kg every second.

28. Waves

Section 28.3

In contrast to a real wave, there is no energy transported from the beginning to the end in a wave of dominos. Each domino receives energy from the gravitational field.

Like a real wave, a wave of dominos also has a carrier and a speed.

Section 28.4

1. Swing: Position and speed of the swing.

A tram traveling back and forth between end-stations: Position of the tram.

A string of a violin: Position, speed of the center of the string.

Woods: Color of the leaves in the course of a year.

Section 28.5

2. From a few millimeters to a few tens of meters.

Section 28.6

1. $\lambda = v/f$ = (300 m/s)/440 Hz = 0.7 m

2. $\lambda = v/f$ = (300 000 km/s)/98.4 MHz = 3 m

Section 28.7

1. Loudspeaker, voice, musical instruments, thunder storm, explosion.

2. 150 Hz

3. 15 m and 15 mm

4. The frequency remains the same, the wavelength increases.

5. About 3000 m

Section 28.8

1. In a lightning bolt, a strong current flows for a very short time. The magnetic field of this current changes very quickly. It detaches from the lightning bolt, moves away as a wave and induces an electric current in a TV antenna.

2. Transmitting antennas of radio and TV stations, parabolic antennas of telecommunications towers, hot oven, light sources, X-ray tubes, radioactive substances.

Section 28.9

1. Wind is not a wave. Two “winds” cannot flow through each other.

2. We get something between a standing wave and a normal wave. On the one hand, we see progressive motion, as in a normal wave. On the other hand, the wave will grow and shrink periodically, as a standing wave does.

3. Given: l = 1 m
v = 6m/s
$\lambda_{max} = 2l$ = 2 m

To obtain two nodes, we need to have $l = 3/2\lambda$, i.e., $\lambda = 2/3 l$ = 2/3 m.

From $v = \lambda f$ we get

$f = v/\lambda$ = 9 Hz

4. If the waves oscillate “in step”: We get a wave having double the amplitude of a single wave.

If they oscillate “out of step”, we have complete extinction.

29. Photons

Section 29.4

1.

a) $E = h \cdot f = 6.6 \cdot 10^{-34}$ Js $\cdot$ $9.84 \cdot 10^{7}$ Hz

$= 6.494 \cdot 10^{-26}$ J

$$p = \frac{h \cdot f}{c} = \frac{E}{c} = \frac{6.494 \cdot 10^{-26}\,\text{J}}{3 \cdot 10^{8}\,\text{m/s}} = 2.16 \cdot 10^{-34}\,\text{Hy}$$

b)

$$E = \frac{h \cdot c}{\lambda} = \frac{6.6 \cdot 10^{-34}\,\text{Js} \cdot 3 \cdot 10^{8}\,\text{m/s}}{1.5 \cdot 10^{-10}\,\text{m}} = 1.32 \cdot 10^{-15}\,\text{J}$$

$$p = \frac{h}{\lambda} = \frac{6.6 \cdot 10^{-34}\,\text{Js}}{1.5 \cdot 10^{-10}\,\text{m}} = 4.4 \cdot 10^{-24}\,\text{Hy}$$

c) $E_{\text{SWF3}}/E_{\text{visible}} = p_{\text{SWF3}}/p_{\text{visible}} \approx 10^{-7}$

$E_{\text{X-rays}}/E_{\text{visible}} = p_{\text{X-rays}}/p_{\text{visible}} \approx 10^{4}$

2. a) A current of negative momentum flows with the water jet into the ball (positive direction is down). The positive momentum from the gravitational field and the negative momentum from the water jet balance each other.

b) A current of negative momentum flows with light into the small sphere. The positive momentum from the gravitational field and the negative momentum from the light balance each other.

c) Every second, a quantity of

$p = 7 \cdot 10^{-11}$ Hy

flows into the small sphere via the gravitational field.

A photon carries an amount of momentum of

$p_{\text{Ph}} = 8.25 \cdot 10^{-28}$ Hy.

(See textbook.)

$$n = \frac{p}{p_{\text{Ph}}} = \frac{7 \cdot 10^{-11}}{8.25 \cdot 10^{-28}} \approx 10^{17}$$

Some 10^{17} photons must hit the sphere every second. (The exact value depends upon how the light is reflected and refracted by the sphere.)

30. Atoms

Section 30.1

$$\frac{12\ 000\ \text{km}}{50\ 000} = 0.24\ \text{km} = 240\ \text{m}$$

Section 30.4

1.

$$E = \frac{h \cdot c}{\lambda} = \frac{6.6 \cdot 10^{-34}\,\text{Js} \cdot 3 \cdot 10^{8}\,\text{m/s}}{2.85 \cdot 10^{-7}\,\text{m}} = 6.95 \cdot 10^{-19}\,\text{J}$$

2. The ionization energy of a sodium atom is $0.8 \cdot 10^{-18}$ J (see textbook).

$$\lambda = \frac{h \cdot c}{E} = \frac{6.6 \cdot 10^{-34}\,\text{Js} \cdot 3 \cdot 10^{8}\,\text{m/s}}{0.8 \cdot 10^{-18}\,\text{J}} = 2.475 \cdot 10^{-7}\,\text{m} = 247.5\ \text{nm}$$

This is UV light.

31. Solid substances

Section 31.2

$m/n = 58.5$ g/mol

$\rho = m/V = 2.16$ g/cm^3

$$\frac{m/V}{m/n} = \frac{n}{V} = \frac{2.16\ \text{mol}}{58.5\ \text{cm}^3} = 0.0369\ \text{mol/cm}^3 = 36.9 \cdot 10^{-6}\ \text{mol/mm}^3$$

1 mol corresponds to $6.02 \cdot 10^{23}$ particles

Z = Number of particles

$$\frac{Z_{\text{NaCl}}}{V} = 2.2 \cdot 10^{19}\ \frac{\text{molecules}}{\text{mm}^3} = 4.4 \cdot 10^{19}\ \frac{\text{atoms}}{\text{mm}^3}$$

Section 31.10

Negative terminal connected to the control electrode.

32. Nuclei

Section 32.1

1. $V_A = 8 \cdot V_B$
$r_A = 2 \cdot r_B$

2. $\rho = 10^{14}$ g/cm^3 = 10^{17} kg/m^3
$r = 5000$ m

$$V = \frac{4}{3}\pi r^2 \approx 5 \cdot 10^{11}\,\text{m}^3$$

$$m = \rho \cdot V = 10^{17}\,\frac{\text{kg}}{\text{m}^3} \cdot 5 \cdot 10^{11}\,\text{m}^3 = 5 \cdot 10^{28}\,\text{kg}$$

Section 32.2

2. The ratio of number of protons and neutrons is close to 1 for light elements. For heavy elements, it is smaller than 1.

3. There are about 286 stable nuclides.

4. The heaviest stable nuclide is ${}^{238}_{92}U$.

5. The stable isotopes of neon are: ${}^{20}_{10}Ne$, ${}^{21}_{10}Ne$ and ${}^{22}_{10}Ne$.

6. Technetium (Number of protons: 43)

7. Xenon has 36 isotopes, 9 of these are stable.

Section 32.3

1. $m_{Tl} = 350 \cdot 10^{-27}$ kg = $3.5 \cdot 10^{-25}$ kg

a) $E = 10^{-18}$ J

$$m_{\text{excitation}} = \frac{E}{k} = \frac{10^{-18}\,\text{J}}{9 \cdot 10^{16}\,\text{J/kg}} \approx 10^{-35}\,\text{kg}$$

$$\frac{m_{\text{excitation}}}{m_{Tl}} = \frac{10^{-35}}{3.5 \cdot 10^{-25}} \approx 3 \cdot 10^{-11}$$

b) $E = 10^{-14}$ J

$$m_{\text{excitation}} = \frac{E}{k} = \frac{10^{-14}\,\text{J}}{9 \cdot 10^{16}\,\text{J/kg}} \approx 10^{-31}\,\text{kg}$$

$$\frac{m_{\text{excitation}}}{m_{Tl}} = \frac{10^{-31}}{3.5 \cdot 10^{-25}} \approx 3 \cdot 10^{-7}$$

2. The mass of 1 mol of a substance is of the order of 100 g. As a result of the excitation, the mass increases by 1/10^7, i.e., its mass changes by 100g/10^7 = 10 µg. The analytical balance at school reacts to 100 µg at best.

Section 32.4

2. When a neutron is added to a nucleus, we normally gain energy. Only in the case of ${}^{4}_{2}He$ do we have to supply energy when a neutron is added.

Section 32.7

2.

$p + \bar{p} \rightarrow e + \bar{e}$

$p + \bar{p} \rightarrow 2e + 2\bar{e}$

$p + \bar{p} \rightarrow n + \bar{n}$

Section 32.8

1.

	pn	p + n
$-E_S$ (pJ)	− 0.359	0
Sum (pJ)	− 0.359	0

	pn	2p + e + $\bar{\nu}$
Rest energy (pJ)	n 150.5349	n 150.5277 e 0.0819
$-E_S$ (pJ)	− 0.359	0
Sum (pJ)	150.1759	150.4096

	pn	2n + $\bar{e}$ + ν
Rest energy (pJ)	p 150.3277	n 150.5349 $\bar{e}$ 0.0819
$-E_S$ (pJ)	− 0.359	0
Sum (pJ)	149.9687	150.6168

Deuterium cannot decay according to any of the three reactions.

2.

	$p_{19}n_{21}$	p_9n_{11} + $p_{10}n_{10}$
$-E_S$ (pJ)	− 54.72	− 24.74 − 25.74
Sum (pJ)	− 54.72	− 50.48

	$p_{19}n_{21}$	p_2n_2 + $p_{17}n_{19}$
$-E_S$ (pJ)	−54.72	− 4.53 − 49.15
Sum (pJ)	− 54.72	− 53.68

	$p_{19}n_{21}$	$p_{20}n_{20}$ + e + $\bar{\nu}$
Rest energy (pJ)	n 150.5349	p 150.3277 e 0.0819
$-E_S$ (pJ)	− 54.72	− 54.80
Sum (pJ)	95.815	95.610

	$p_{19}n_{21}$	$p_{18}n_{22}$ + $\bar{e}$ + ν
Rest energy (pJ)	p 150.3277	n 150.5349 $\bar{e}$ 0.0819
$-E_S$ (pJ)	− 54.72	− 55.08
Sum (pJ)	95.608	95.537

The potassium isotope can decay according to the latter two reactions.

3.

	p_6n_8	p_2n_4 + p_4n_4
$-E_S$ (pJ)	− 16.87	− 4.69 − 9.05
Sum (pJ)	− 16.87	− 13.74

	p_6n_8	$2p_3n_4$
$-E_S$ (pJ)	− 16.87	− 2 · 6.29
Sum (pJ)	− 16.87	− 12.58

Neither one of the reactions is possible.

4.

	4p	p_2n_2 + $2\bar{e}$ + 2ν
Rest energy (pJ)	p 2 · 150.3277	n 2 · 150.5349 $\bar{e}$ 2 · 0.0819
$-E_S$ (pJ)	0	− 4.5334
Sum (pJ)	300.655	296.700

Two anti-electrons and two neutrinos are produced in addition to the helium nucleus.

Section 32.9

1. a)

	$p_{29}n_{32}$	$p_{30}n_{31}$ + e + $\bar{\nu}$
Rest energy (pJ)	n 150.5349	p 150.3277 e 0.0819
$-E_S$ (pJ)	− 85.18	− 84.15
Sum (pJ)	64.355	66.260

	$p_{29}n_{32}$	$p_{28}n_{33}$ + $\bar{e}$ + ν
Rest energy (pJ)	p 150.3277	n 150.5349 $\bar{e}$ 0.0819
$-E_S$ (pJ)	− 85.18	− 85.66
Sum (pJ)	65.148	64.957

	$p_{29}n_{32}$	$p_{27}n_{30}$ + p_2n_2
$-E_S$ (pJ)	− 85.18	− 79.83 − 4.5334
Sum (pJ)	− 85.18	− 84.36

The decay of ${}^{61}_{29}Cu$ produces $\bar{e}$.

b)

	$p_{29}n_{37}$	$p_{30}n_{36}$ + e + $\bar{\nu}$
Rest energy (pJ)	n 150.5349	p 150.3277 e 0.0819
$-E_S$ (pJ)	− 92.33	− 92.63
Sum (pJ)	58.205	57.78

	$p_{29}n_{37}$	$p_{28}n_{38}$ + $\bar{e}$ + ν
Rest energy (pJ)	p 150.3277	n 150.5349 $\bar{e}$ 0.0819
$-E_S$ (pJ)	− 92.33	− 92.42
Sum (pJ)	57.998	58.197

	$p_{29}n_{37}$	$p_{27}n_{35}$ + p_2n_2
$-E_S$ (pJ)	− 92.33	− 86.63 − 4.5334
Sum (pJ)	− 92.33	− 91.16

The decay of ${}^{66}_{29}Cu$ produces e.

c) The decay that produces an electron cannot be investigated since the separation energy of $p_{91}n_{137}$ is not shown in the table.

	$p_{90}n_{138}$	$p_{89}n_{139}$ + $\bar{e}$ + ν
Rest energy (pJ)	p 150.3277	n 150.5349 $\bar{e}$ 0.0819
$-E_S$ (pJ)	− 279.27	− 279.05
Sum (pJ)	− 128.94	− 128.43

	$p_{90}n_{138}$	$p_{88}n_{136}$ + p_2n_2
$-E_S$ (pJ)	− 279.27	− 275.62 − 4.5334
Sum (pJ)	− 279.27	− 280.15

The decay of ${}^{228}_{90}Th$ produces ${}^{4}_{2}He_K$.

2.

	$p_{26}n_{29}e_{26}$	$p_{25}n_{30}e_{26}$ + ν
Electric charge	26 − 26	25 − 25
Baryonic charge	26 + 29	25 + 30
Leptonic charge	26	25 + 1

An electron of the shell reacts with a proton of the nucleus. The neutron produced remains in the nucleus, the neutrino flies off.

3.

a) A is above the stable nuclides. B is diagonally below A (to the right).

b) C is below the stable nuclides. D is diagonally above C (to the left).

c) E is at the top right on the nuclide chart. F is two positions below and two positions left of E.

Section 32.10

${}^{238}_{92}U$: 99.28 %

${}^{235}_{92}U$: 0.72 %

$$\frac{m}{n} = 238\,\frac{\text{g}}{\text{mol}}$$

$$n_{\text{total}} = \frac{m}{238\,\text{g/mol}} = \frac{1\text{kg}}{0.238\,\text{kg}}\text{mol} = 4.2\text{ mol}$$

$$n_{235} = 0.072 \cdot 4.2\text{ mol} = 0.03\text{ mol}$$

$$I_n = 5.76 \cdot 10^5\,\text{Bq} = 5.76 \cdot 10^5 \cdot \frac{1}{6} \cdot 10^{-23}\,\frac{\text{mol}}{\text{s}} = 0.96 \cdot 10^{-18}\,\text{mol/s}$$

n' is 1% of the amount of ${}^{235}_{92}U$.

$$t = \frac{n'}{I_n} = \frac{3 \cdot 10^{-4}\text{ mol}}{0.96 \cdot 10^{-18}\text{ mol/s}} = 3.125 \cdot 10^{14}\text{ s}$$
$$= 0.868 \cdot 10^{11}\,\text{h} = 3.6 \cdot 10^9\,\text{d} = 10^7\text{ years}$$

Section 32.11

1. 25 000 years

2. 6 years

3. 1 month

4.

0 years	A: 100%	B: 0%	C: 0%
2 years	A: 0%	B: 100%	C: 0%
1 000 000 years	A: 0%	B: 0%	C: 100%

5. The conversion rate decreases to half its initial value.

Section 32.12

1. See Exercise **4** of Section 32.8. When a ${}^{4}_{2}He$ -nucleus is formed, 3.956 pJ are emitted.

1 mol contains 6.022 ·10^{23} nuclei. The energy E_K emitted when 1 mol is formed is:

$E_K = 6.022 \cdot 10^{23} \cdot 3.956 \cdot 10^{-12}$ J = $2.38 \cdot 10^{12}$ J

Compare to the reaction

$2H_2 + O_2 \rightarrow 2H_2O$

The chemical tension of this reaction is:

$\mu(A) - \mu(B) = 474.36$ kG

When 1 mol of H_2 burns, the reaction conversion is $n(R) = 0.5$ mol. Therefore, the energy E_H released is:

$E_H = [\mu(A) - \mu(B)] \cdot n(R)$
$= 474.36 \cdot 0.5$ kJ = 237 kJ

The ratio of the two energies is:

$$\frac{E_K}{E_H} = \frac{2.38 \cdot 10^{12}\,\text{J}}{2.37 \cdot 10^5\,\text{J}} \approx 10^7$$

2. An average energy current of 100 W flows through a human. Almost all the energy is used for entropy production. Assume a volume of 100 l for a human. Then we have

$$\frac{P}{V} = 1\,\frac{\text{W}}{\text{l}}.$$

For the Sun:

$$\frac{P}{V} = 0.01\,\frac{\text{W}}{\text{l}}.$$

1 l of human emits 100 times the energy of 1 l of Sun.

Section 32.13

1. The energy released as a result of the decay of uranium was calculated in the textbook:

$\Delta E_{\text{Uranium}} = 32.07$ pJ

	$p_{56}n_{85}$	$p_{57}n_{84}$ + e + $\bar{\nu}$
Rest energy (pJ)	n 150.5349	p 150.3277 e 0.0819
$-E_S$ (pJ)	− 188.09	− 188.49
Sum (pJ)	− 37.555	− 38.080

$\Delta E_{\text{Barium}} = 0.525$ pJ.

$$\frac{\Delta E_{\text{Uranium}}}{\Delta E_{\text{Barium}}} = \frac{32.07}{0.525} \approx 61$$

2.

	Ba	La	Ce	Pr
30 s	a lot	little	very little	very little
18 min	medium	medium	little	very little
5 d	very little	little	a lot	little
1 a	very little	very little	little	a lot