Chapter 1
Basic Principles

I think the facts leave no doubt that the very mightiest among the chemical forces are of electric origin. The atoms cling to their electric charges, and opposite electric charges cling to each other.
Hermann von Helmholtz, 1881

Electrodynamics is the topic on which most of physics is based. The physics subtopics such as mechanics, wave motion, thermodynamics, atomic physics and so on all have their origin in the electric force. Pressure and temperature, sound, material bending, winds, atomic and molecular structure etc. are basically the effects of interactions between electric charges, together with all our senses and our physiology in its entirety, including the genetic code. Observations beyond the senses are made with instruments whose design is based exclusively on electrodynamics. So when physicists study subatomic dynamics and discover two other types of interactions, the strong nuclear force that holds nucleons together and the weak atomic force causing fusion and radioactive decay, this is done with senses and instruments whose function is based on the electric force.

Electrodynamics is, together with gravity, the force controlling everyday life. One major issue of physics is whether these two forces have a common origin. Rephrased: is there a relationship between mass and charge; could it be that the one is generated dynamically from the other? For those who are interested in basic research, issues of this nature are particularly favourable for fruitful research projects.

Also gravity is experienced through the electric force. As you read this, you may sit in a chair and feel the so-called normal forces, which are electric and arise indirectly via your weight. But when gravity acts alone, such as in a free fall, it is not experienced; you are 'weightless'.

Electrodynamics is based on the concept of electric charge, which has its origin in the electrons and protons of the atom and is the source of the electromagnetic force. All macroscopic charge is composed of these elementary charges and the attraction between them is the condition for the bonded system known as the atom. Consequently, also molecules are formed through the electric interaction.

Throughout this book the mutual interaction between charged objects is emphasized. These appear 'pairwise', i.e. they interact two by two, according to Newton's

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fundamental laws of nature. The dynamics of nature is then a sum of individual pairwise interactions. This summation requires knowledge of the interaction between any two fundamental items such as two electrons, both at rest and in general motion. In electrodynamics there is a good, although not complete, knowledge about this force, which in the latter case, moving charges, essentially has been observed in closed conductors.

As a complement to the force view of nature, physics may be described by the energy concept, defined through the pairwise interaction via the concept of work. The result of work is stored energy U in the system (also known as potential energy). Force and energy are intimately connected via the energy principle from which force F arises as an energy minimization:

$$\bar{F} = -\nabla U \tag{1.1}$$

i.e. force is the negative gradient of the stored energy U. This principle is one cornerstone of physics. Force is in turn defined by Newton's laws of motion:

$$\bar{F} = \frac{d}{dt}(m\bar{v}) \tag{1.2}$$

i.e. force is the time derivative of momentum. Formula (1.2) also defines inertial mass which is a measure of an object's resistance to motional change. Furthermore, the scientific definition of time and space originates from this formula.

Force and energy form the core of physics. Since energy is a scalar it is computationally advantageous to first obtain this quantity and then to use the energy principle (1.1) to achieve the desirable force vector. In this book, this technique is used extensively and a prior knowledge in the two concepts is essential.

1.1 Exercises

1.1 a. Apply the energy principle, formula (1.1), in case of free fall toward the earth's surface. Explain the origin of the potential energy and how it generates the active force.
   b. Use (1.1) to determine the force acting on the falling object and the earth.
   c. Identify the forms of energy involved in the dynamics. What became of the energy in the final state, i.e. when the object is located on the ground?
   d. Why is the motion of the earth usually neglected? Reflect upon how Newton's third law (action and reaction) is affected by this neglect.

1.2 a. Explain why a heavier object has a shorter fall time than a lighter one if they are released from the same high altitude above the earth.
   b. There is a famous film recorded on the moon where the principle of equal fall time for different weights is tested and verified. What is the difference

in conditions between the earth and the moon? (Ref: see web link on the book's website).

1.3 a. Explain what is meant by the concepts of gravitational and inertial mass. Give examples of phenomena where the first and second is at work. How are they related to each other?
b. Find out what Mach's principle means and explain in your own words how the inertial mass arises from the gravitational. (Ref: see web link on the book's website).

1.4 a. A space station is located at about 400 km above the earth's surface. Estimate the gravitational force on a person at this height. Explain why a person staying on a space station can be regarded as being in a weightless condition.
b. Check with what amount a measurement with a balance of a 1 kg mass would change if it were measured at an altitude of 100 m compared to at the ground. Would it be possible to perform this measurement and thereby verify the distance dependence of gravity?

1.5 Explain why the coriolis and centrifugal forces must be regarded as fictitious forces. Give examples of phenomena in which these concepts are used.

1.6 What is meant by the term 'relative motion'? Could there be any form of absolute motion?

1.7 How would you define the concept of time? How are clocks made?

1.8 What does the concept 'space' mean to you? What is meant by distance and how is it measured?

1.9 If a movie is playing at a slower speed, any motion in the movie is seen consistently slower. How does that influence your perception of time in the movie?

Further Readings

A.K.T. Assis, *Relational Mechanics*, (Apeiron Montreal, 1999)
A.P. French, *Newtonian Mechanics*, The MIT Introductory Physics Series, (Norton, New York, 1971)

Recommended Mathematical Handbooks

M.R. Spiegel, *Mathematical Handbook*, (McGraw-Hill, 1968)
R.K. Wangsness, *Electromagnetic fields*, (Ch. 1), (Wiley, 1986)

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