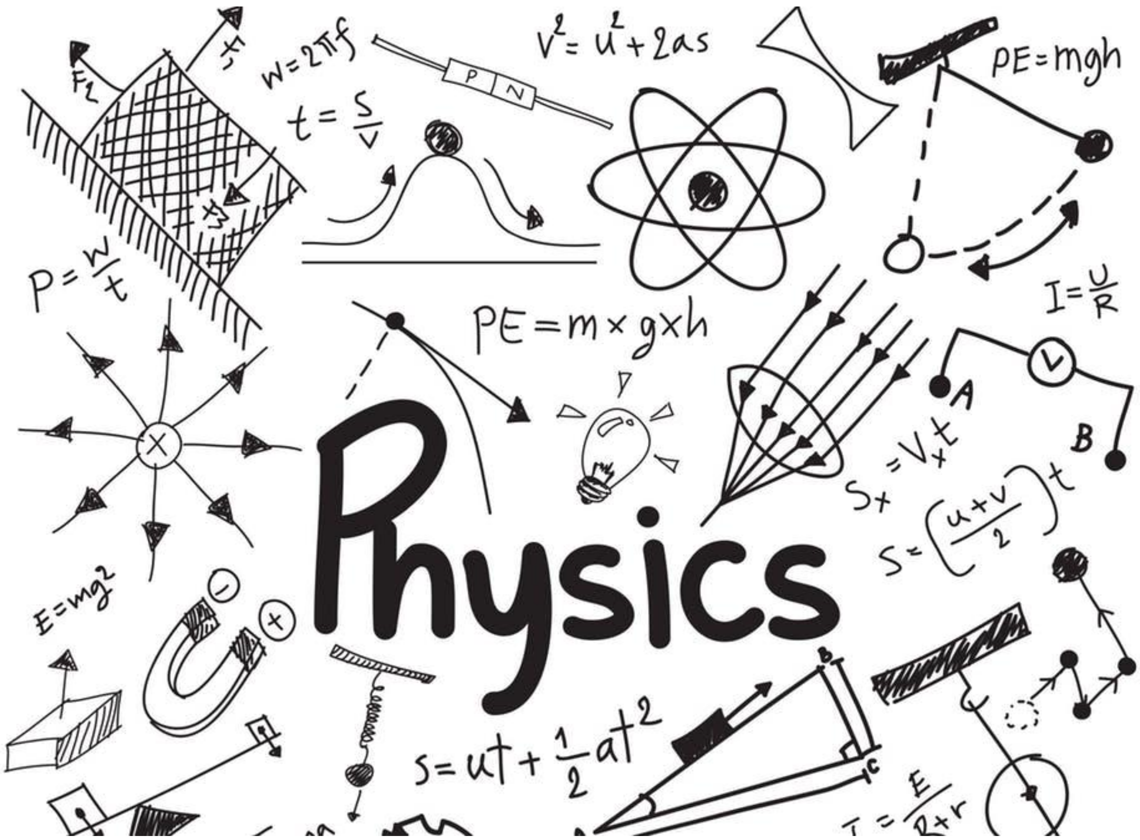


Pre Diploma Program

VASA ÖVNINGSKOLA/IB SECTION

M. Norrby et. al | 2018

Table of Contents

PHP1: Physics as a natural science

Welcome to our PHP1 physics booklet! This is the result of many iterations of trying to find and create teaching material at a suitable level.

The course PHP1 follows the Finish national curriculum course Physics 1, with some adjustments to better prepare students for the IB diploma program. It gives an overview of physics and its role in society, skims the surface of the smallest of the small and the biggest of the big (the structures of the atom and of the universe) and lays the foundation for working with motion and forces.

This is a work in progress building on the experience and effort of many physics teachers at our school, please forgive the mistakes that are bound to be found, and do give feedback on how the material could be made better.

Live long and prosper!

- The authors (M. Norrby, E. Strömbäck, J. v. Wright, T. Illman)

1. Physics – an experimental science

The history pf physics

The development of physics is closely related to the development of our society and culture. Many of the most famous people of all time have been scientist, expanding our world view and making new inventions.

As with many things the roots of physics can be traced back to ancient Greece. The Greek philosophers did a lot of work with what was called natural philosophy to understand nature. But during this time experiments was not something done by educated men, and therefore some of their ideas were way off, while other ideas turned out to be pretty good.

Only during the renaissance did modern science start to take form. Gradually scientists started to realize the importance of own experiments to understand different phenomena. The Italian scientist Galileo Galilei (1564-1642) is sometimes counted as the father of experimental science and his impacts on the world view of his day is immense.

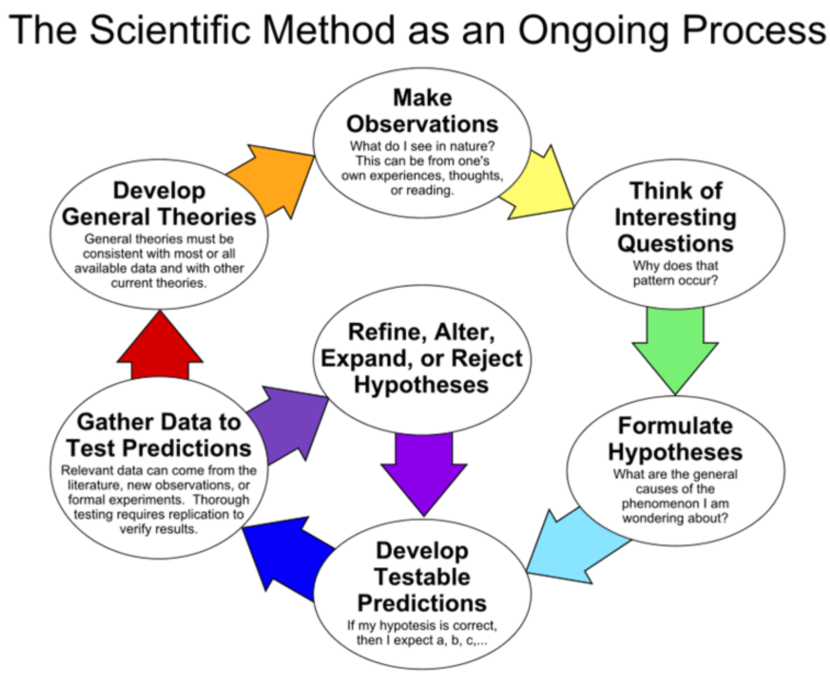
Building on these and other contemporary insights, the English scientist Isaac Newton (1643-1727) compiled and expanded current knowledge of mechanics in a book called "Philosophiæ Naturalis Principia Mathematica" (or just "Principia") which still today holds as a foundation for our everyday understanding of the universe.

After this human knowledge about physics rapidly expanded through the work of many famous scientists and inventors. But at the end of the 19th century some problems were found that could not be explained with traditional physics. This led to the discovery of what today is known as general relativity and quantum mechanics. These branches of physics lay the foundation for our current world view and makes things like computers and GPS possible. Albert Einstein is one of the names often associated with this revolution, together with Marie Curie and many other scientists of the 20th century.

But as our knowledge expands, the number of unanswered questions also grows. There is still a lot to be discovered by future scientist, maybe more than ever known before! Things like dark matter, dark energy, the arrow of time and merging relativity with quantum theory pose many questions and the answers found to these questions might again change our world view many times over. This it the challenge given to young people today aiming to be scientists!

The scientific method

Whether something is trustworthy knowledge in Physics is decided by observations of reality and experimental tests. The method usually implemented all through the sciences is called "the scientific method" and consists of several distinct steps.



By ArchonMagnus - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=42164616

1. Observe nature (e.g. lying on the ground looking at the sky)
2. Find something that makes you curious (e.g. white clouds)
3. Formulate a **research question** (e.g. why do clouds seem white?)
4. Guess one answer to your question, the guess is called **a hypothesis** in fancy scientific language (e.g. clouds are made of marshmallows)
5. Construct an experiment to test your hypothesis (e.g. fly an open airplane through a cloud with your mouth open and see if it tastes sweet)
6. If your test is negative, then make another guess (a new hypothesis) and test that one instead
7. If your test is positive, design a different experiment to test the same hypothesis. When you have done many experiments and they all are positive, over time you can start calling your hypothesis a **theory**

Exercises:

101 Find the approximate time periods and discoveries associated with the following scientists: Isaac Newton, Nicolaus Copernicus, Galileo Galilei, Aristotle, Johannes Kepler, Albert Einstein, Marie Curie, Peter Higgs

102 Construct your own creative hypothesis to the question "Why do clouds seem white?" and describe at least one experiment to test the hypothesis

2. Measurements and uncertainties

Significant figures

The result of a measurements is **a value and a unit**. For example, the length of a person can be given as 177 cm. This is given with three significant figures. With a more precise method we might reach the value 176.8 cm (four s.f.). On the other hand, we may also want to round the value to 180 cm (two s.f.).

Note that leading zeroes are not significant (so 0.0023 m has two s.f.). On the other hand, trailing zeroes are significant in a value with decimals (so 320.0 m has four s.f.). Trailing zeroes in an integer may or may not be significant (3200 m has two s.f., or three, or four), and without additional information we have to assume the worst, in this case only two s.f.

Measurements

In order to make a good measurement, you should

- make it very clear what exactly is to be measured
- figure out suitable instruments
- repeat the measurement several times
- figure out a reasonable final result including uncertainty

Experimental uncertainty

When making measurements, we can get **systematic errors** and **random errors**. Systematic errors occur when all measurements are wrong in the same direction and by the same amount. The reason can be that the instrument is badly adjusted, for example a bathroom scale that does not show 0 (zero) when nobody is standing on it, or a measurement of the outdoor temperature when the sun is shining straight on the thermometer. A systematic error could also mean that there is an error in the way the experiment is performed.

Random errors often occur when repeated measurements give results that vary. Random errors are unavoidable when humans read off instruments but they can also be caused by the instruments themselves or by fluctuations in the experimental conditions.

Assume that we have a measurement result of 5.0 metres, but with an error (uncertainty) of 0.5 metres. We write this as

Distance: $s = 5.0 \pm 0.5$ m

We can talk about the error in two different ways:

- the absolute error or uncertainty is 0.5 m
- the relative error or uncertainty is 0.5m/5.0m = 0.1 = 10%

Absolute uncertainties are usually given in results (e.g., 5.0 ± 0.5 m) but relative uncertainties are needed in certain error calculations. Absolute uncertainties are typically given with one significant figure only (so 5.0 ± 0.5 is all right, but 5.0 ± 1.8 is not).

Finding the uncertainty in a measurement

There are different ways of determining the uncertainty in a measurement, and the circumstances must be used to decide which way should be used.

For individual measurements we can often use half the limit of reading. For example, for a ruler with 1 mm between the lines, the absolute error is 0.5 mm.

In some situations this is clearly too optimistic and we have to use common sense or some general guidelines. For example, when measuring time with a hand-held stop watch that gives the result with an accuracy of 0.01 s, we must take into account the uncertainty of human reaction and guess at, e.g., ±0.2 s.

For some instruments the uncertainty is stated in the manual (it may even be printed somewhere on the instrument itself).

Improving on uncertainty

If we measure the same quantity repeatedly, we can use the mean deviation from the mean value, called the mean residual as the uncertainty of the measurement.

Example: Five people have measured the mass of an object. Their results are 0.56 g, 0.58 g, 0.58 g, 0.55 g, 0.59 g. Calculate the mean value and the mean deviation.

The mean value (the average) is

$$\frac{(0.56 + 0.58 + 0.58 + 0.55 + 0.59)g}{5} = 0.572\ g$$

To calculate the mean deviation, we will calculate the mean of the positive deviations from the mean value.

$$\frac{|0.56 - 0.572| + |0.58 - 0.572| + |0.58 - 0.572| + |0.55 - 0.572| + |0.59 - 0.572|}{5} = 0.014\ g$$

The mean deviation is 0.014 g. We round the uncertainty (upwards) to one significant figure (≈ 0.02 g) and then round the mean value to the same number of decimals, and the result is 0.57 ± 0.02 g.

In some situations, we get measurements that are obviously wrong. This can happen when measuring a distance, e.g., if some object has been inadvertently moved. It can also happen with electronic equipment. Such outliers can be dropped from calculations, but they should be mentioned in the report of an investigation and the reason for dropping them should be given.

Comparison with uncertainties

Example: Alban and Berg wants to see who is taller. Alban measures Berg's height to 178.6 ± 0.4 cm and Berg measures Alban's height to 177.5 ± 1.0 cm. This means that Berg's real height is in the range 178.2 – 179.2 cm and Alban's in 176.5 – 178.5 cm. These to ranges overlap (in 178.2 – 178.5 cm) so we cannot say for sure that Berg is taller than Alban.

Exercises

201 (a) The length of a person is given as 170 ± 1 cm. What is the relative uncertainty?

(b) The mass of a stone is 780 g with an uncertainty of 2 %. Write the mass using the ± notation.

202 A stone is put on an electronic scale with results in whole grams. The reading is 123 g.

(a) Write the measurement value with uncertainty.

(b) What is the relative uncertainty?

203 One group of researchers claim that the age of the universe is $(13.70 \pm 0.15) \times 10^9$ years while another group claims that it is $(14.2 \pm 1.5) \times 10^9$ years. Are these claims in conflict with each other?

204 The length of a corridor is measured by five students. The results, measured in meters: 36.4; 36.0; 35.9;36.5; 36.3. Calculate the mean and the mean deviation from the measurements.

205 Six people measure the time it takes for a sprinter to run 300 m. The results of the measurements are: 33.3 s; 31.0 s; 34.3 s; 35.0 s; 31.6 s; 32.1 s.

Determine the mean time

The absolute uncertainty

The relative uncertainty

206 Minilab: Measure the length and width of a sheet of A4 paper, with uncertainties. Then calculate the area of the paper, with uncertainty.

207 Minilab: Drop an object five times from 2m height and measure the time it takes to fall to the floor. Give the result as a value of the form $t \pm \Delta t$. Give the time with an uncertainty that is the greatest residual (the greatest deviation from the average, see the example in the text).

208 Minilab: in groups of 5: How accurate is your measurements of time with a stop watch? Repeat minilab 207 so that you measure the time once, with five different stop watches (every member of the group has one).

209 Minilab: Each student measures the weight of a stone! Gather the information from the whole group. Calculate average weight, absolute error and relative error.

210 Minilab: An A4 paper is dropped from the same height (1.5 m) 10 times. Determine the time it takes to drop the paper.

3. The SI system

Quantity, unit, prefix

The concepts of Physics can be used to describe both living organisms and dead objects. A fish can be 10 cm long and so can a stone or a nail. Thus, length is a physical quantity – something that can be measured and stated in a number (integer or decimal) of some unit. The unit often contains a prefix (like the “centi” in centimetre) which shows the relationship to some other unit (in this case metre) for the same quantity.

Basic quantities and derived quantities

The SI system (an abbreviation from the French name: Système international (d'unités)) is an international system of units, is used in most scientific contexts and it is slowly replacing older systems (cgs, imperial units, etc.).

The SI system has the following basic quantities and corresponding basic units:

Quantity	***Common symbol***	***Unit***	***Abbreviation***
mass	*m*	*kilogramme*	*kg*
length	*l, x, s*	*metre*	*m*
time	*t, T*	*second*	*s*
electric current	*I*	*ampere*	*A*
temperature	*T, t*	*kelvin*	*K*
amount of substance	*n*	*mole*	*mol*
luminous intensity	*I*	*candela*	*cd*

Note that the same quantity can be indicated by different symbols in different contexts, and that a letter can mean many different things (for example, m can stand for mass, metre or milli-). The unit kilogramme is the only basic unit with a prefix in it.

In addition to the basic quantities, there are many derived quantities, some of which have their own name. Some examples:

Quantity	*common symbol*	*basic unit*	*abbreviation*
area	*A*	*m2*	-
volume	*V*	*m3*	-
velocity	*v*	*m/s*	-
density	*ρ*	*kg/m3*	-
force	*F*	kgm/s^2	*N (newton)*
pressure	*P*	N/m^2	*Pa (pascal)*

(The symbol ρ is the Greek letter rho.)

Furthermore, in everyday life many quantities are measured in non-standard units, like minutes and hours for time (instead of kiloseconds!), degrees centigrade/Celsius for temperature, and litre for volume (instead of dm3). Sometimes prefixes are used with these non-standard units (like 1 ml = 1 millilitre).

Example: In many countries distances are measured in inches, feet, yards and miles.

A mile is 1609.3 m and a mile is 1760 yards. How long a yard is in meters?

So one since a mile is 1609.3 meters and there should also be 1760 yards in that same distance:

1 yard=1609.3/1760=0.914375 m≈0.9144 m= 91.44 cm

Prefixes and powers of 10

The value of a quantity can be expressed in many different ways, e.g., a distance s = 5000 m = 5 km = 5 x 10^3 m. The following prefixes are common:

Smaller prefixes			***Larger prefixes***		
deci	*d*	10^{-1}	*deca*	*da*	10^{1}
centi	*c*	10^{-2}	*hecto*	*h*	10^{2}
milli	*m*	10^{-3}	*kilo*	*k*	10^{3}
mikro	*µ (my)*	10^{-6}	*mega*	*M*	10^{6}
nano	*n*	10^{-9}	*giga*	*G*	10^{9}
pico	*p*	10^{-12}	*tera*	*T*	10^{12}

In everyday life (and in Physics) we are sometimes interested in a general approximation of a quantity, rather than an exact value. We can then give the order of magnitude of the quantity, meaning the nearest power of ten. For example, the distance from the Earth to the Sun (approximately 150 million km) can be given as 1011 m, and the mass of a proton (9.1×10^{-31} kg) as 10^{-30} kg.

Vector quantities and scalar quantities

There are two basic types of quantities (this is true both for basic and for derived quantities):

Vector quantities have both magnitude and direction: e.g., velocity (the wind blows with 7 m/s from the north) or force (I lift the box using an upward force of 25 N).

Scalar quantities have only magnitude (the temperature is 25 degrees Celsius; it took me 40 seconds to run across the yard).

Sometimes positive and negative numbers are used to describe the direction for vector quantities. Once we have agreed (arbitrarily) that upwards is the positive direction, then the force mentioned in the example is +25 N, while a force of the same magnitude in the opposite direction would be -25 N. However, negative numbers can also be included in the scale for a scalar quantity. The temperature can be -25 C, but that only means that it is 25 degrees below some temperature that we have agreed to call zero (the freezing point of water). Time is considered a scalar quantity since it only “moves” in one direction; “forward”.

Unit conversions

1 mile = 1609 m	*1 gallon (US) = 3.785 liters*	*1 stone = 6.35 kg*
1 ft = 30.48 cm	*1 gallon (UK) = 4.546 liters*	*1 lb = 454 g*
1 in = 2.54 cm	*1 fl oz = 29.57 ml*	*1 oz = 28.3 g*
1 nautical mile = 1852 m	*1 kWh = 3.6 MJ*	*1 hp = 745.7 W*

Exercises

301. On the preceding page there are rules for converting between some standard and some non-standard units. What do the following abbreviations in the rules stand for:

ft, in, lb, oz, fl oz, W, J, kWh, hp

302. Use the conversion rules (see the last page) to convert

(a) 5.0 miles into kilometers

(e) 8 UK gallons into liters

(b) 6.50 nautical miles into kilometers

(c) 9 stone into kilograms

(d) 5 ft 11 in to centimeters

(f) 280 MWh into J

(g) 10 kW into horse powers

(h) 74 kg into stones and pounds

303. Use the conversion rules to convert

(a) 55 mph (miles per hour) in km/h

(b) 120 km/h to mph

(c) 23 m/s into knots (1 knot is one nautical mile per hour)

(d) 48 psi (pounds per square inch) to kg/m2

304. Write the following quantities using suitable prefixes. Example: 0.0025 m should be written as 2.5 mm.

(a) The power of a power plant, 15 000 000 W

(b) The frequency of a microprocessor, 3 400 000 000 Hz

(c) The thickness of a human hair, 0,000 0028 m

(d) The volume of a drop of ink in an ink jet printer, 0,000 000 000 040 liters

305. Write the values in previous question with powers of ten.

306. How many times (appoximately) has your heart beaten during your life, if it typically beats 70 times per minute? Give the answer as an order of magnitude (i.e., to the closest power of 10)

307. Find the prefixes used for orders of magnitude

(a) 10^{-15}, 10^{-18} etc

(b) 10^{15}, 10^{18} etc

308. Search the internet for definitions of the following units

(a) mole (mol)

(b) decibel (dB)

4. Spreadsheets and graphs

Spreadsheet programs (such as Excel) are a universal tool, useful in the analysis of experimental measurement values, theoretical analyses, simulations, etc. Modern calculators can also be used to store data in tables and perform simple statistical analyses. Most data logging systems give measurements in the form of files that can be directly imported into a spreadsheet or into a calculator. But a lot of experiments are just as well done using conventional equipment, with measurement values written down in a lab journal and then entered by hand into a spreadsheet.

Assume that we are working with a uniform motion, s = vt, and we have made the following observations of distance s in metres as a function of the time t in second:

t/s	***s/m***
5	*9.1*
10	*20.3*
15	*28.2*
20	*42.4*
25	*51.1*

Note that the units are not entered with the values into the spreadsheet – t/s means that the quantity is t (time) and the unit is s (seconds).

When you are creating a graph you should think about at what axis the data should be placed. Both y=f(x) and "y as a function of x", indicates that which axis is which, quite clearly. Distance as a function of time (s(t) or an (t, s)-graph) therefore also means that the time should be on the x-axis and the distance on the y-axis. The distance changes when the time changes. To simplify your life, enter the measurements that you want to appear on the x-axis in the first column and the measurements you want to appear on the y-axis in the second column in a spreadsheet.

We can enter these values into an Excel spreadsheet (depending on the settings, you might need to use a decimal comma rather than a decimal point). Note that units should not be included in the same cells as the numeric values, since Excel then treats the value as text rather than as numbers:

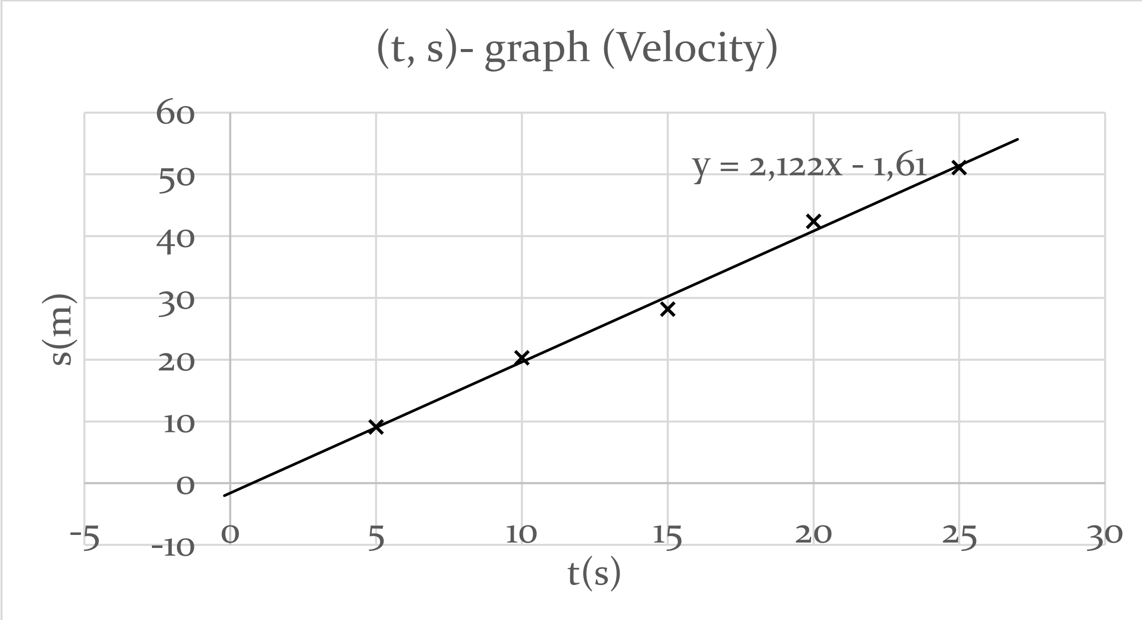
time/s	distance/m
5	9.1
10	20.3
15	28.2
20	42.4
25	51.1

To fit a simple linear model to these data we let Excel create a chart:

- select the data cells
- Insert chart (press chart symbol)
- choose XY (Scatter) without a line

When you have a first version of the graph, you can edit axis labels, graph title, gridlines, etc. Most importantly, by right-hand clicking on one of the data points, you can choose "Add trendline" with Type = linear and Option "display equation on chart". The best-fit line will be shown to be $y = 2.1x - 1.6$ which shows that if the motion was uniform, then its velocity is estimated to be 2.1 m/s.

The slope of the equation gives the velocity since we have a (t, s)- graph. (For each second that passes the distance increases uniformly). The intersection with the y-axis (the constant in the equation) shows the distance at $t = 0$ s.



Error bars can also be added to the data points to show the uncertainties, using the option "Format Data Series". Uncertainties are given separately for the x- and the y-direction, and they can be given as an absolute value or a percentage.

Exercises

401. Edith measured the volume and the mass of five pieces of wood and got the following results:

Piece number	Volume (cm^3)	Mass (g)
1	38	30
2	51	45
3	98	77
4	65	53
5	80	68

Make a spreadsheet table with this data and produce (and interpret) a graph.

402. A group of students emptied a water container through a pipe in the bottom of the container. The diameter of the pipe could be varied, and the students registered the time it took to empty the container (t) as a function of the diameter (d) of the pipe. The results were as follows:

d / cm	1.5	2.0	3.0	4.0	5.0
t / s	73.2	41.1	18.3	10.0	6.8

Make a spreadsheet with this data. Add a best-fit line according to an exponential model – what does the equation for the best-fit line tell?

403. The table below shows the air resistance on a bicycle at different speeds.

Speed (m/s)	0	1	2	3	4	5
Friction (N)	0	10	30	70	130	200

Make a spreadsheet with this data and produce a graph. Add a best-fit line (which is NOT a straight line in this case). Then add a column with the squared values of the time variable and produce a new graph with t^2 on the horizontal axis and s on the vertical axis. What is the best-fit line in this graph?

404. Make a spreadsheet with the below data. Add a best-fit line and the equation for it.

a. What does the equation for the best-fit line tell, what kind of motion is this?
b. Write down the equation for the best-fit line.
c. Give a value for the distance at t = 0.5 s
d. What would the distance be for t = 2 s?
e. Is the result reliable?

d / m	1.3	1.9	4.3	4.8	6.1
t / s	0.2	0.4	0.6	0.8	1.0

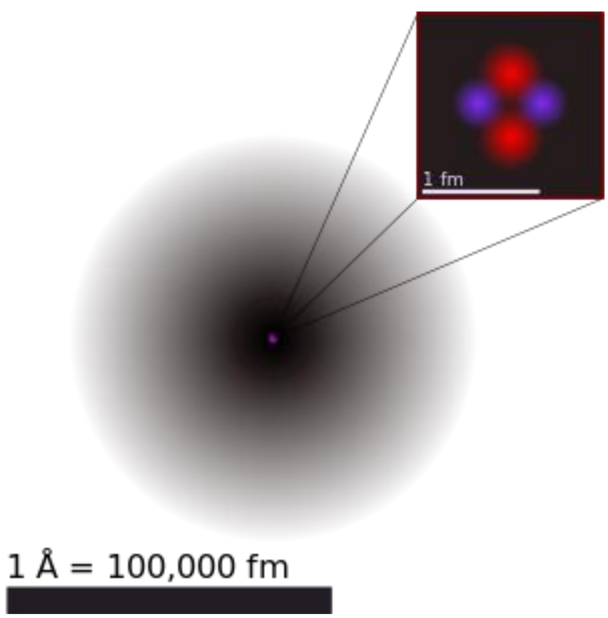
5. The structure of matter

The question what everything is made of has intrigued humans throughout history. The suggestions for answers have varied. The idea of four elements (earth, water, wind, fire) was developed by the ancient Greeks and remained popular throughout medieval times, even though idea of atoms is almost as old.

It was only in the 19th century that the modern view of the structure of matter started to take form. First the known elements were ordered in the periodic system by Mendeleiev and at the end of the 19th century radioactivity and the first elementary particles were discovered.

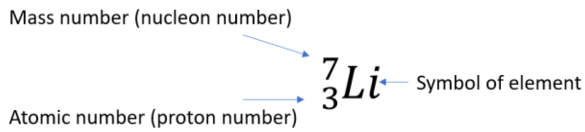
The atom

The word atom comes from the Greek word for "indivisible" and stands for the smallest possible building block of matter. We know it to consist of protons and neutrons in a tiny nucleus at the center, with an electron "cloud" around it. This picture is the result of the work of a long chain of scientists in the early 20th century, starting with the Thomson model (or "plum pudding" model) and the Rutherford "planetary" model towards the quantum mechanical description of Bohr, Heisenberg and Schrödinger. The atom still is the basis for our basic understanding of matter and for all chemistry and, even though it was later proven to be devisable into many smaller parts as described by the standard model.



An illustration of the helium atom, depicting the nucleus (pink) and the electron cloud distribution (black). (https://en.wikipedia.org/wiki/Atom)

We usually represent atoms in the following standard form:



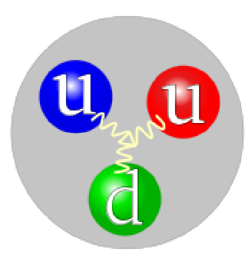
The atomic number (or proton number) tells us which chemical element we are dealing with, and is often left out since the elemental symbol tells us the same thing. The mass number (or nucleon number) tells us how many protons and neutrons together make up the nucleus of the atom (protons and neutrons have the common name nucleons). Using the mass number and atomic number we can easily calculate the number of neutrons present in a nucleus.

Atoms of the same element (same number of protons) but different number of neutrons are called isotopes. For example ^{6}Li, ^{7}Li and ^{8}Li would all be called isotopes of lithium, with 3, 4 or 5 neutrons respectively.

The standard model

Our current knowledge is summarized in what is called the standard model of particle physics. It includes twelve particles (six quarks and six leptons) and four forces (with their corresponding carrier particles). Recently the Higgs boson was also experimentally discovered and added to the model to account for the mass of the particles. In addition, all of these particles have their anti-particles with similar properties but opposite charge.

Using two of the quarks (up and down) and the electron we can build all atoms. The other particles of the model usually only appear in high-energy experiments or in cosmic rays, but they have to be there to make the model compete.



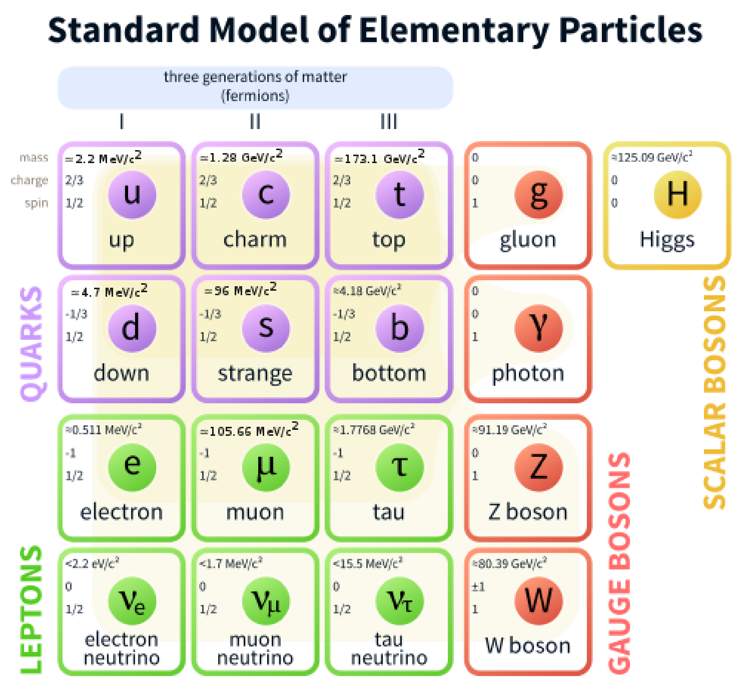
A proton is composed of two up quarks, one down quark, and the gluons that mediate the forces "binding" them together. (https://en.wikipedia.org/wiki/Quark)

The model also states that all interactions in the universe can be broken down into four basic forces:

- Gravity: between objects of mass
- Electromagnetic: between objects of charge
- Weak (nuclear): responsible for the beta decay
- Strong (nuclear): keeps the nucleus together

Of these four only the first two can be experienced in our everyday life. We all instinctively know how gravity works. The electromagnetic force is what keeps molecules together and separate materials apart.

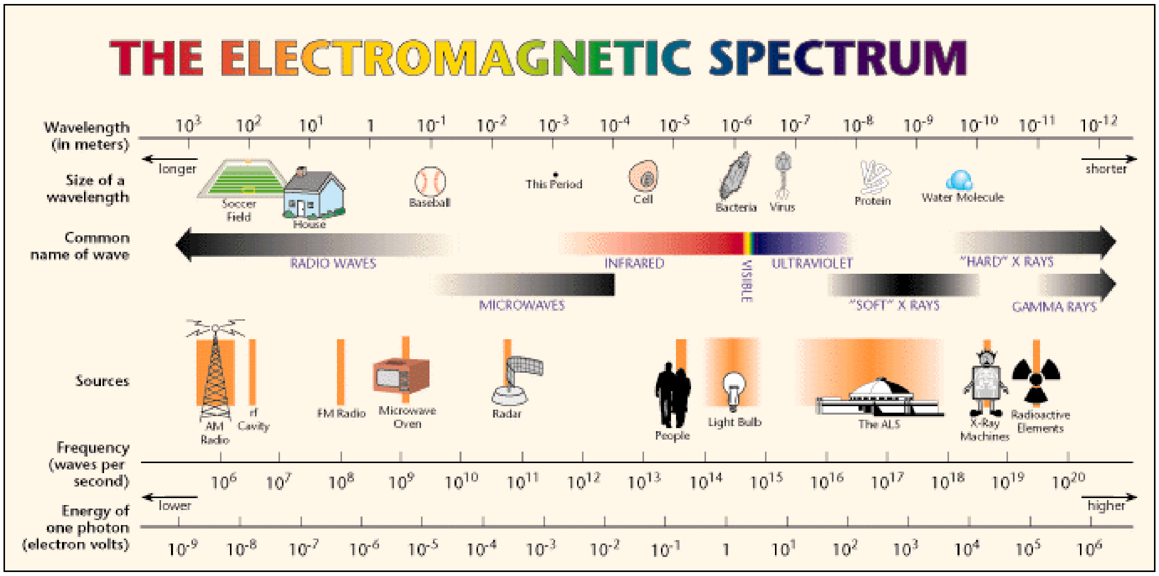
The standard model has been very successful in explaining the known matter in the universe, but it is known to be incomplete. One of the main problems is that gravity is not directly included in the model, another is the mystery of dark matter in the universe. To solve these problems many theories are being developed, including string theory which might some day be able to explain all of these different particles as vibrations of one kind of cosmic strings.



https://upload.wikimedia.org/wikipedia/commons/thumb/0/00/Standard_Model_of_Elementary_Particles.svg/502px-Standard_Model_of_Elementary_Particles.svg.png

Radiation and radioactivity

There are two main kinds of radiation, electromagnetic radiation and particle radiation. Electromagnetic radiation is a wave phenomenon with different properties (and names) depending on the wavelength: radio waves, micro waves, infrared radiation, visible light, ultraviolet, X-rays and gamma rays.



http://www2.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

Particle radiation on the other hand is simply a stream of particles at high speed.

If a nucleus has "the wrong" combination of protons and neutrons, it will spontaneously and randomly fall apart. A particle will be sent out at high speed and the element will change. This is called radioactive decay, or just radioactivity. There are two main types of decay:

- Alpha decay, where an alpha-particle consisting of 2 neutrons + 2 protons is emitted
- Beta decay, where an electron (or positron[1]) is emitted
- As a biproduct, gamma radiation is often emitted

Half-life ($T_{1/2}$) is the time it takes for half the nuclei in a sample to decay. Activity (A) gives the number of decays per second (in Becquerel, Bq) for a radioactive sample.

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[1] The positron is the antiparticle of the electron, having the same properties but positive charge

Exercises

501 Research the ancient Greek idea of the four elements

502 Describe the problems with the Rutherford atomic model and the postulates Bohr made to overcome the problems.

503 Use the simulation http://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html to

- Build a stable neutral atom with 4 protons
- Build a stable neutral atom with 6 neutrons
- Build an ion with 6 electrons
- Find 2 elements with 3 stable isotopes

504 Find the year of discovery of each of the twelve particles of matter in the standard model.

505 Find the halflife and type of radiactive decay for

a) ^{238}U
b) ^{14}C
c) ^{15}O

506 Research ionizing radiation, what kinds of radiation belong to this category and why are these so dangerous?

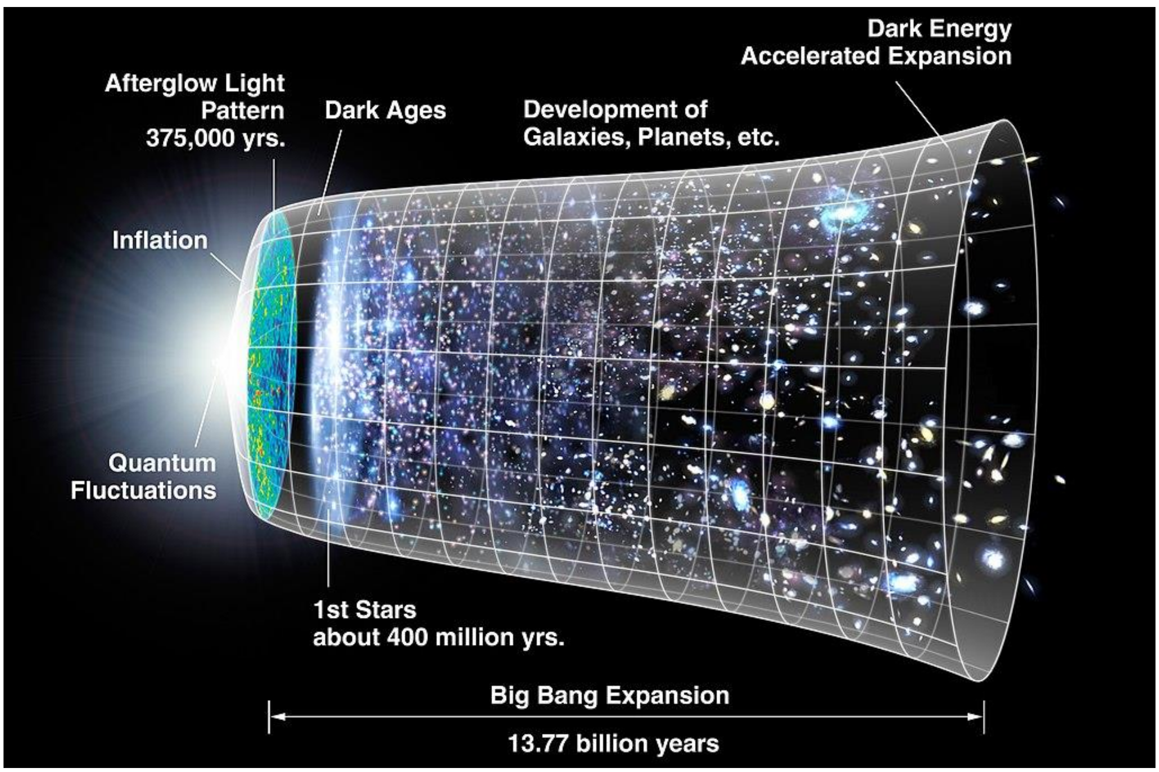
507 Which are the main sources of background radiation in Finland?

508 What is radon gas, where does it come from and why is it dangerous?

6. The universe

According to current theories our universe started about 13.7 billion years ago with an event now called the Big Bang. The Big Bang theory is often misunderstood as some form of explosion spreading matter throughout space, but this is far from the idea of the theory. The main results of this strange event was that time and space came into existence, together with a large amount of energy, some of which later condensed into hydrogen and helium atoms. The three dimensions of space started expanding and still continue to expand at an accelerating pace.

Some of the hydrogen and helium atoms formed stars, and through the fusion processes inside these stars heavier elements were created. At the end of the life cycle of a star it can explode, throwing the heavier elements out into space around it. This process can repeat itself several times before there is enough matter around a newly formed star to also form planets.



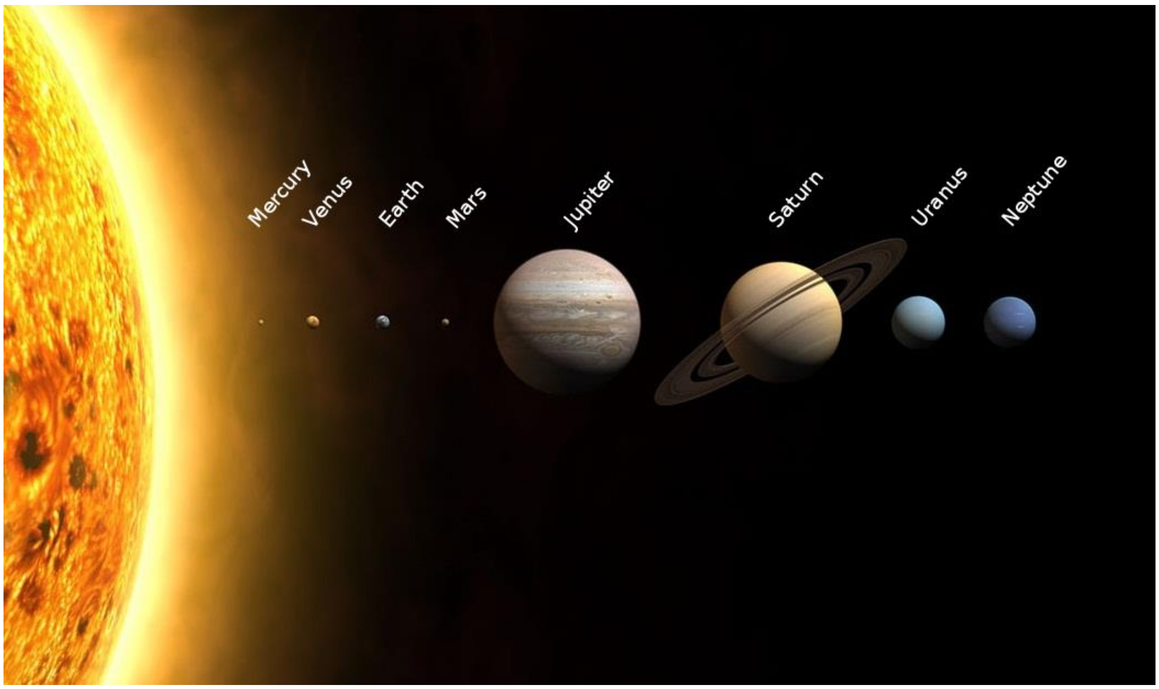
A short overview of the history of the universe. (https://en.wikipedia.org/wiki/Big_Bang)

The universe is probably infinite in size, but we can only ever know and observe the region around us which we call the observable universe. This region of space contains about 100 billion galaxies with roughly 100 billion stars per galaxy. Our own galaxy is called the Milky Way, a bar spiral galaxy containing about 400 billion stars.

Our star system

Our star, which we call the sun, is a very ordinary star, slightly below average in size, a bit further out than half way from the center of the Milky Way galaxy. We call the region of space dominated by the gravity of this star "The solar system".

There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune. The four inner planets are "rocky planets", they are all relatively close to the sun and quite small. The outer planets are gas giants without a solid surface, much further away from the sun.



The planets of the solar system. The distance between the planets is NOT to scale. (https://en.wikipedia.org/wiki/Solar_System)

Most of the planets have moons, earth has one and e.g. Jupiter has 64. Between the planets there are also asteroids, comets and space dust.

Excercises

601 Research the evidence supporting the Big Bang theory.

602 What is the cosmic microwave background?

603 Compare the creation stories of four major world religions.

604 What is an exoplanet?

605 Use http://exoplanets.org/ to find out the current number of confirmed exoplanets. List the different techniques to discover exoplanets.

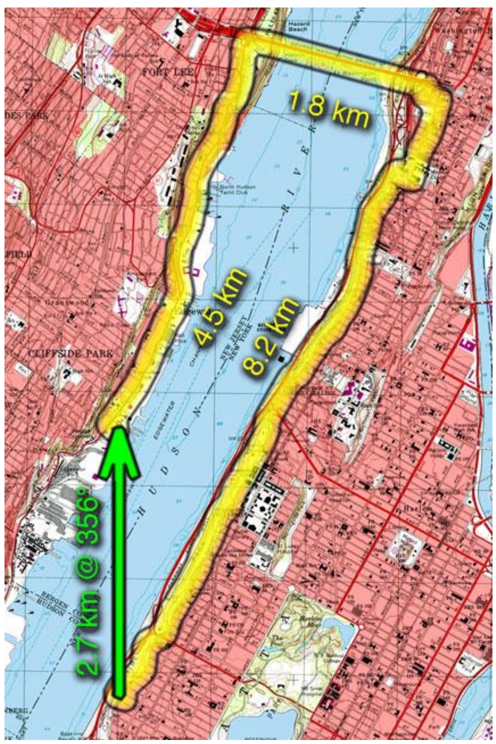
7. Displacement and velocity

Distance and displacement

There are two different ways of describing where something is or how long it has moved from some agreed-upon starting point.

Distance (sträcka/avstånd, etäisyys) = how far the object has moved along the path that is has taken from the starting point, regardless of whether this motion was in a straight line or not. For example, the odometer in a car indicates distance. Distance is a **scalar quantity**.

Displacement (lägesändring, siirtymä) = how far the object has moved in a straight line (”as the crow flies”), e.g., the length of the line segment between the starting point and the final point. For a car journey, this is what you get if you measure the distance from the starting point to the goal with a ruler on a map. Displacement is a **vector quantity**.



The distance traveled is a reasonable 14 km, but the resultant displacement is a mere 2.7 km north. The end of this journey is actually visible from the start. Maybe the traveler should buy a canoe. Source: http://physics.info/displacement/

Speed and velocity

To describe how fast an object is moving, we can talk about

- speed = distance / time (scalar quantity)
- velocity = displacement / time (vector quantity)

The symbol v is used for both and the formula is $\boldsymbol{v = s / t}$ or

Average velocity: $v_{ave} = \frac{s}{t}$

The unit for speed and for velocity is 1 m/s. Since velocity is a vector quantity, there will also be a direction associated with the unit.

In everyday life, other units are also used (e.g., 1 km/h, 1 mph, and 1 knot). Since 1 km/h = 1000m / 3600s we get the following conversion rule:

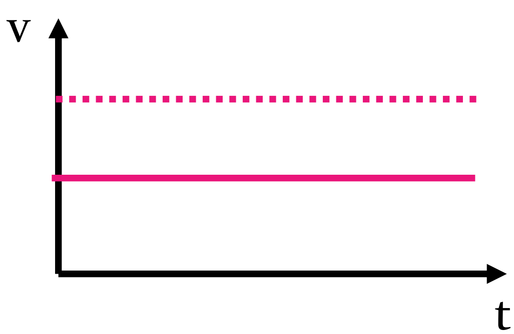
km/h to m/s : divide by 3.6 m/s to km/h : multiply by 3.6

A simple way to remember this rule is to think of a sprinter who runs 100 m in 10 s, so his speed is 10 m/s. Is he then running at 10×3.6 = 36 km/h or 10/3.6 = 2.8 km/h?

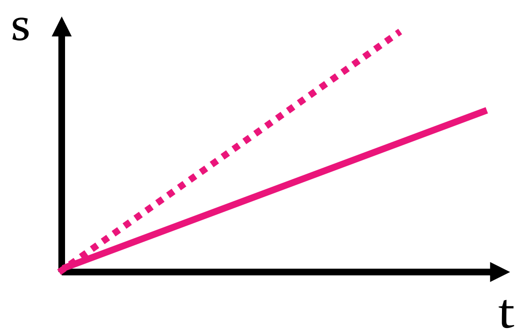
Instant velocity is an idealised concept – in real life we always work with **mean velocity** (average velocity) over some time. When a piece of technological equipment (like a GPS or the speedometer of a car) says that the instant velocity is 80 km/h it is really giving the mean velocity over a short time.

In real-world motion, the velocity of an object is not constant over time. But in Physics we often deal with idealised situations, and we can imagine a velocity being constant over any period of time.

If the velocity of an object is constant – both its magnitude and its direction – then we speak about *uniform motion (UM).*



Velocity-time graph



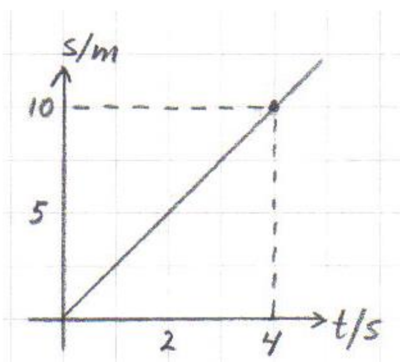
Displacement-time graph

In a graph illustrating velocity as a function of time – a *velocity-time graph* – uniform motion is described by a horizontal line. The higher up the line is, the greater the velocity. Zero velocity means that the object is not moving at all. Since velocity is a vector quantity, it can also be negative, and then we have a horizontal line below the *t*-axis. The rectangular area under the graph represents the displacement $s = vt$.

In a graph illustrating displacement as a function of time – *a displacement-time graph* – uniform motion is described by a straight line with a gradient. The steeper the line, the greater the velocity. If the velocity is negative then the line slopes downward.

***Example*:**

The graph below illustrates the distance moved by a toy car on a track. The displacement in 4 seconds is 10 metres, and the velocity (the gradient of the line) is 2.5 m/s.



Calculations in physics

When solving problems in physics there are certain principles to follow.

1. State all the starting values, do unit conversions if necessary
2. Find a suitable formula, show the raw formula, do formula manipulations if necessary
3. Show your calculations step by step
4. Give a clear answer with correct unit and rounding

Example: A car drives 250 km in 3.0 h, what is the average speed?

1. s = 250 km
   t = 3.0 h

2. $v_{ave} = \frac{s}{t}$

3. $v_{ave} = \frac{250}{3} = 83{,}333 \ldots km/h \approx 83 km/h$

4. Answer: average speed is 83 km/h

Exercises

701. Fidel walks from a point by a circular lake (radius 65 m) to the opposite point, along the shore. What is

(a) his displacement?
(b) the distance he has walked?

702. Aida first walks 650 m to the North and then 850 m to the West. How far is she then from her starting point?

703. Figaro first walks 1 km N, then 1 km NE and finally 1 km E. How far is he from where he started?

704. A snail climbs up a flagpole, moving up 2 m every day and sliding down 1 m every night.

(a) What is its displacement in 24 hours?

(b) If the pole is 5 m high, how long does it take to reach the top?

(c) What is the total distance the snail has moved when it reaches the top?

705. Heather is out cycling and her average speed is 18 km/h.

(a) How far does she cycle in 3 hours?
(b) How far does she cycle in 40 minutes?
(c) How long does it take her to cycle 10 km?
(d) Convert her speed to m/s

707. The Earth orbits around the sun once every 365 days. Light travels at 300000 km/s. If it takes light 8 minutes to travel from the sun to the Earth,

(a) What is the length of the Earth's orbit (the perimeter of a circle, $p = 2\pi r$)?

(b) What is the orbital speed of the Earth?

708. The Earth spins around its axis once every 24 hours. If the perimeter of the Earth is 40000 km, how fast does a person on the equator move?

709. Assume that a snail can move at approximately 0.4 mm/s. Estimate the width of a typical countryside road and calculate how long it would take the snail to cross the road.

710. In a 100 meter dash the winner's time was 9.99 seconds and the time of the runner-up was 10.03 s. What was the distance between the two runners at the finish line?

711. Gina walks to the West with 4.5 m/s on a boat that moves at 6.0 m/s to the South. What is Gina's speed with respect to the water?

712. A tennis player can hit a serve at 200 km/h. How fast must the opponent react if the dimensions of a tennis court are 27×78 ft?

713. Draw time-displacement diagrams corresponding to the following:

(a) Bruce walks from home to school with constant velocity, except when he stops for a minute at a red light. The walk takes 10 minutes.
(b) Edith (Bruce's mother) walks together with Bruce to the traffic light, but when they have crossed the road she turns around and walks back home.

714. Draw time-velocity diagrams corresponding to the stories in problem 713

8. Acceleration

If the velocity of a motion changes from one moment to another, the rate of change is also a vector quantity, called acceleration a:

$$a = \frac{v - u}{t} = \frac{\Delta v}{t}$$

Where:

u = initial velocity (sometimes the symbol v_0 is used)

v = final velocity

Δv = change in velocity

t = the time it took for the velocity to change from u till v.

If $u > v$ then the acceleration is negative (also called retardation or deceleration). The unit of acceleration is **1 m/s²** (this is mathematically the same as 1 m/s per second: 1 (m/s)/s = 1 m/(ss) = 1 m/s²).

Example: If a car accelerates from 0 m/s to 28 m/s (approx. 100 km/h) in 12 seconds, then its (mean) acceleration is

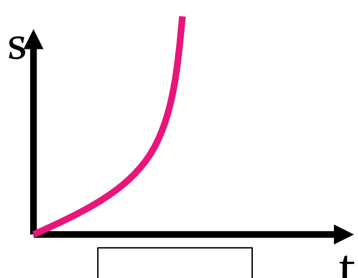
$$a = \frac{v - u}{t} = \frac{28 - 0}{12} = 2.3\ m/s^2$$

If the acceleration is the same over a period of time, we talk about *uniformly accelerated motion*. (UAM).

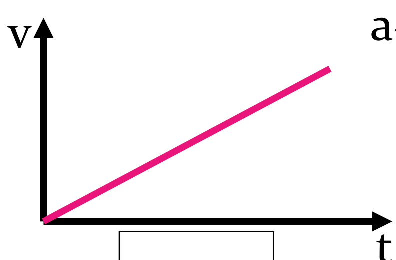
The equation above can be rewritten as

$$v = u + at \text{ (in the IB-formula booklet)}$$

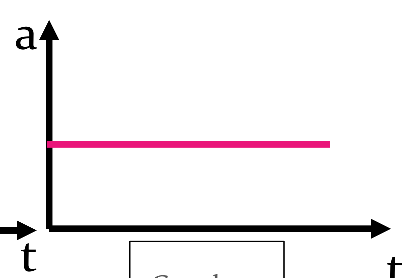
The graphs below show a uniformly accelerated motion.



Graph 2



Graph 3



Graph 4

Graph 2, distance (s) as a function of time (t): Since the velocity changes all the time, we get a curve that becomes steeper all the time. Thus, it cannot be a straight line, but an upward bending curve (for positive acceleration). Mathematically, such a shape is described by squaring the *x*-variable (a parabola).

Graph 3, velocity (v) as a function of time (t): Since the velocity changes all the time uniformly, we get a line. The slope of the line is the acceleration of the motion.

Graph 4, acceleration (a) as a function of time (t): Since it is a uniformly accelerated motion, the motion has a constant acceleration and therefore we get a horizontal line.

Equation of free fall

An object in free fall near the surface of the Earth will accelerate with acceleration g = 9.8 m/s². This is always true for all objects, if the air resistance is so small that it can be ignored. In realistic situations, air resistance can be ignored if the object is small and heavy, and the velocity is not very big.

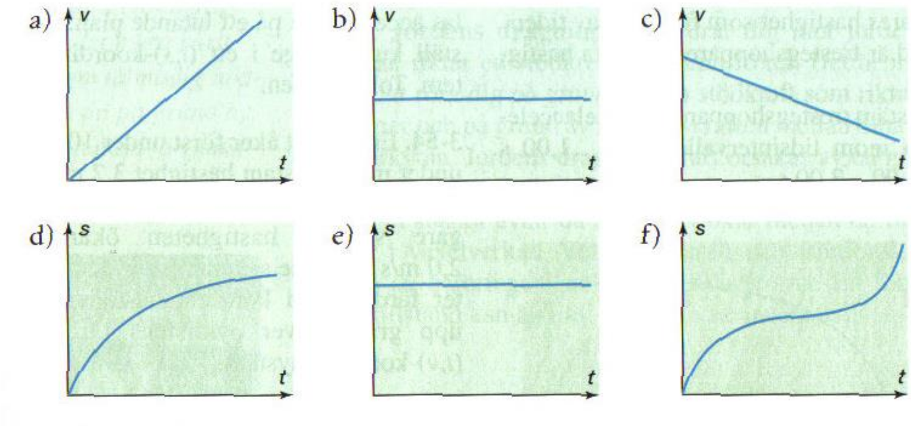
Example: If a stone is dropped from a rooftop, and it takes 2.5 seconds for it to reach the ground, with what speed does it hit the ground?

$$\mathrm{a} = \frac{\Delta v}{t}$$
$$\Delta v = a \cdot t = g \cdot t = 9.8 \cdot 2.5 = 24.5\ ms^{-1}$$
$$Final\ speed\ \approx 25\ ms^{-1}$$

Note that the acceleration of free fall is independent of the mass of the object. In practice, air resistance will affect different objects differently – the formula considers the ideal case when there is no air resistance at all.

Exercises

801. Describe in words the motions illustrated by the six diagrams below.



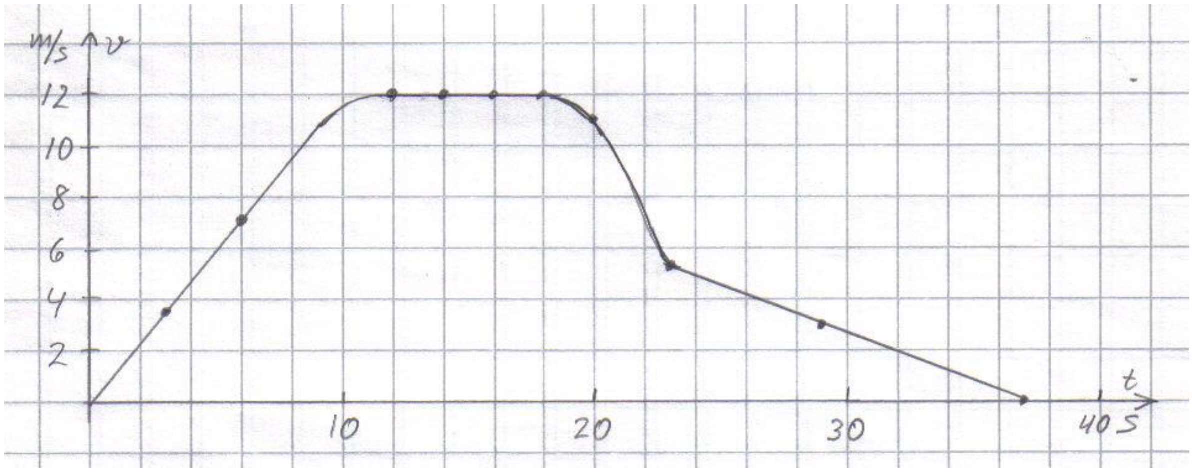
802. A swimmer in a 50 m race had the following times during her race:

s/m	0	5	10	20	30	40	50
t/s	0.0	1.4	3.9	9.4	16.8	24.9	32.6

(a) Plot the data points in a (t,s) graph.
(b) Create a new table with the swimmer's mean velocities in the intervals 0..10 s, 10..20 s etc.
(c) Sketch a (t,v) graph
(d) Why does the swimmer's velocity vary the way it does?

803. If a car goes from 0 km/h to 100 km/h in seven seconds, what is its acceleration (in m/s^2)? How many ***g*** is this, when ***g*** = 9.8 m/s^2?

804. The graph below describes a car starting at a traffic light.
(a) Interpret the graph in words.
(b) What is the average acceleration of the car in the interval 0..10 s?
(c) What is the average acceleration of the car in the interval 18..24 s?
(d) How far does the car travel during the interval 12..18 s?
(e) How far does the car travel during the interval 0..10 s?



805. A stone falls from a rooftop 46 m above the ground (starting from rest). What is its velocity when it touches down?

806. Wilma is cycling with a constant velocity of 3.2 m/s. After this, there is a downhill, where the velocity increases with 2.0 m/s during 4.0 seconds. After this, she continues with a constant velocity. What is her new velocity=

807. A car with the velocity 55 km/h is driving along a straight road. The driver hits the gas pedal and accelerates uniformly with 1.7 ms^{-2} for 2.5 seconds. Calculate the velocity of the car after the acceleration.

808. A Formula 1 car with the velocity 130 km/h drives into the wall of tires next to the track and stops after 0.14 seconds. Calculate the acceleration for the car during the collision. Suppose that this is a uniformly decelerated motion.

9. Force and Newton's laws

Force is a quantity that describes what

- changes motion (starts a motion, stops it, changes its direction or magnitude)
- changes the shape of objects, e.g., stretching or compressing them

Force is a vector quantity with unit **1 newton = 1 N** and it can be measured with a dynamometer.

The **net force** (total force, resulting force) is the sum of all forces acting on an object, with the directions of the forces taken into account. Often one specific direction is chosen as positive and the opposite direction is considered negative. If the force of gravity pulls an object downwards with force 5 N and we hold it with an upward force of 5 N then the net force is the sum – 5 N + (+5 N) = 0 N (upward).

Forces obey Newton's three laws:

Newton's I Law

If the net force on an object is zero, then its velocity remains constant

This can mean many different things. The first part ("the net force is zero") may be because

- there is no force at all acting on the object
- two or more forces act on the object but they cancel out in all possible directions
-

The second part ("its velocity remains constant") can mean that

- the object is at rest (its velocity has the constant value 0)
- the object is moving and it remains moving with the same speed in the same direction

A situation where Newton's I law is satisfied is called **translational equilibrium**.

Example: A skydiver opens up her parachute and after a few seconds her velocity stabilises and becomes constant, because the two forces (gravity pulling down and the air resistance pushing up) are equal so the net force is zero.

Newton's II law

If the net force on an object is not constant then its velocity will change, and the motion is accelerated. The following relationship holds between net force, mass and acceleration:

$$\boxed{F = ma}$$

This says that

- the greater the force, the greater the acceleration of a car with given mass will be (the net force forward can be increased by trimming the engine, by getting better tyres, by making the shape of the car more aerodynamic, etc), and

- the greater the mass, the smaller the acceleration. A car that is heavier (e.g. because its petrol tank is full or because there are more people in it) has smaller acceleration than a similar car with smaller mass.

Note that acceleration can be negative. A car brakes to slow down when it approaches a turn, and because its velocity becomes smaller the acceleration is negative. Acceleration can also change only the direction of the velocity, leaving its magnitude (shown on the speedometer inside the car) unchanged. This occurs when you drive through a curve with the same reading on the speedometer all the time.

From this we can see that the unit 1 N is really the same as 1 kgm/s^2 (because the unit of mass is 1 kg and the unit of acceleration is 1 m/s^2).

Newton's II law includes all that is said in the first law: if $F = 0$ and m is not zero, then a must be zero and so the velocity is constant.

Example: The velocity of a hockey puck (mass = 170 g) sliding on ice diminishes from 20 m/s to 18 m/s in one second because of friction. That means that its acceleration is (-)2 m/s^2 so the force of friction is $F = ma = 0.17 \times 2 = 0.34$ N

Newton's III law ("the law of action and reaction")

For any two objects A and B the following holds:

If A acts on B with force F then B acts on A with force - F

An example of this is the recoil of a shotgun: the gun acts on the bullet with force F, giving it great acceleration (because its mass is small), while the bullet acts on the gun with force -F giving it only a small acceleration (because its mass is much greater). Rockets also give a good example: the rocket pushes out the exhaust fumes, and they in turn act on the rocket, pushing it forward.

Example: A book with mass 2.0 kg lying on a table is acted upon by the Earth's gravitational pull ($a = 9.8$ m/s^2) by a force $F = ma = 19.6$ N. By Newton's 3rd Law, the book also acts on the Earth with a force of 19.6 N. By Newton's 2nd law, there must be a 19.6 N force acting upwards on the book (because otherwise it would accelerate downwards). This is the **support** force of the table on the book. This support force is called a **normal** force (because it acts at a 90 degree angle to the table surface) and a **reaction** force (it is the reaction force of the 19.6 N force with which the book acts on the table).

Example: When an airplane flies horizontally at constant velocity, there are forces acting on it in four different directions:

- the gravitational force of the Earth (also called the weight of the plane),
- the **lift** force of the air on the airplane (counteracting the weight),
- the **push** originating in the engines, and
- the **drag** (friction between the plane and the air, counteracting the push)

The **weight** W of an object (which is **not** the same as the mass!) is the result of the gravitational force (sometimes written F_G rather than W)

$$W = mg$$

where g = 9.81 m/s² is the acceleration of free fall at the surface of the Earth (which is a measure of the **gravitational field strength**).

Example: A 5.00 kg weight has mass 5.00 kg and weight 5.00×9.8 = 49 N.

Exercises

901. An object has mass 4 kg. What is its weight
   (a) on Earth (g = 9.8 kg/m/s^2)
   (b) on the Moon (where the acceleration of free fall is one sixth of that on Earth)

902. An object with mass 4 kg is dragged at constant velocity along a floor. Draw a picture showing all the forces (there are four of them) acting on the object.

903. What forces act on a tennis ball
   (a) the moment it is thrown up in the air by the serving player
   (b) the moment it reaches the highest point in the air
   (c) the moment it is hit by the racquet
   (d) the moment it hits the surface of the court

904. You place a strong fan on the deck of a sailing boat in calm weather. What happens
   (a) if the fan blows air forward into the sail?
   (b) if the fan blows air backward?

905. Astronaut Scotty whose mass is 75 kg steps on a bathroom scale on Planet X and it says that he weighs 67 kg. What is the gravitational acceleration of Planet X?

906. When a ball flies through the air there are two forces acting on it. Draw a picture which shows the velocity of the ball as a red arrow and the two forces as black arrows.

907. The table below shows the air resistance on a bicycle at different speeds.
   (a) Draw a smooth graph of this data
   (b) How fast can the cyclist travel if she can exert a forward push of 180 N?
   (c) When the cyclist crouches lower she can travel faster. Explain why.

Speed (m/s)	0	1	2	3	4	5
Friction (N)	0	10	30	70	130	200

10. Energy and power

Energy is one of the basic quantities in our universe, something that cannot be created or destroyed. We often use the symbol *E* for energy and the SI-unit is the *joule (J)*. Even though the amount of energy in the universe is constant, there are many different forms of energy and energy can change between these forms. For example, the chemical energy stored in your breakfast cereal is converted to kinetic energy as you bicycle to school, which turns into potential energy when you reach the top of the hill on your way.

Some forms of energy are more useful to us humans than others, e.g. electrical energy and the chemical energy stored in oil which can be used for a lot of different applications, compared to e.g. heat energy which can only really be used to temporarily heat something (which is nice in winter but not very versatile). So when we talk about "saving energy", what we really mean is that we should reduce the use of useful forms of energy since these are in limited supply.

Power (P) is a measure of how fast energy is converted from one form to another, in the unit *watt (W)*. It is calculated by dividing the amount of every by the time it takes to convert it:

$$P = \frac{E}{t}$$

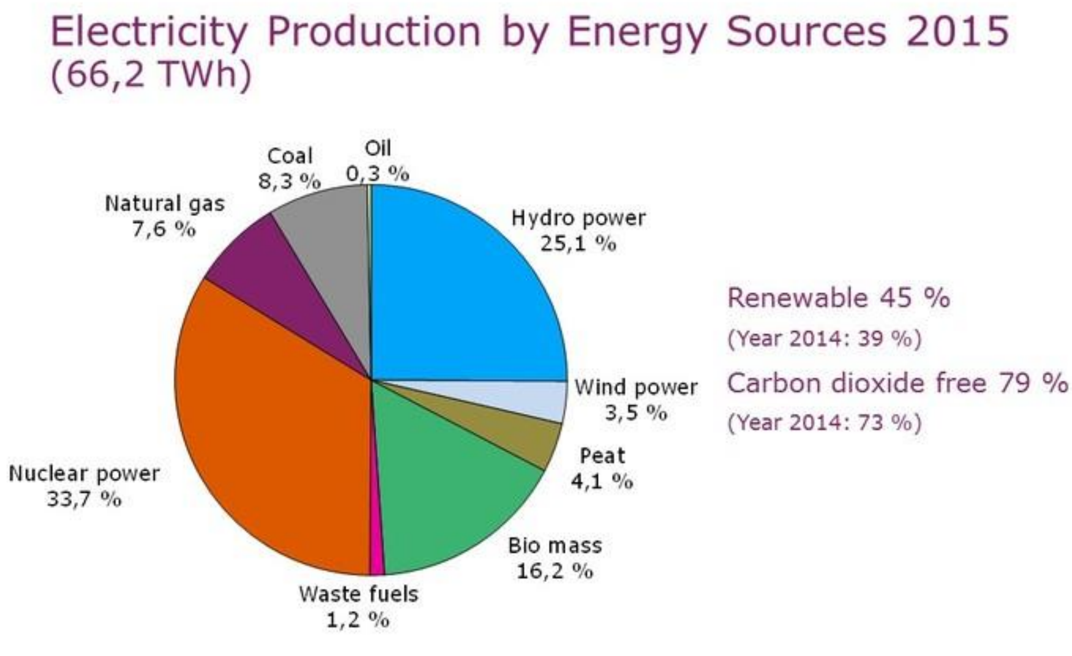
Example: A light bulb has the marking 40W. This means that the light bulb converts 40 J of electrical energy into heat and light energy every second.

1https://all-free-download.com/free-vector/download/light-bulb-illustration_6813703.html

Electrical energy

The energy use (or really the energy transformations) in our society consists of roughly one third electricity, one third fuels for transportation and one third heating. Often we focus on the production and use of electrical energy, since that is so central to our current way of life. Electricity in Finland mainly comes from nuclear power plants and hydroelectric dams. Bio mass and imports also play a large roll, with many other forms of production completing the picture.

Finland is one of the leading countries in Europe when it comes to renewable sources (almost 50%) and carbon free production (almost 80%). This is largely due to the biomass used by the forest industry together with the use of emission free nuclear power and hydroelectric power.



Electricity production in Finland 2015. (Finnish Energy https://energia.fi/en/energy_sector_in_finland/energy_production/electricity_generation)

Exercises

1001. Make a list of all the sources used to produce electricity that you can think of. Categorize these as renewable or non-renewable.

1002. Find out how many horsepower (hp) 100 kW corresponds to.

1003. Find out where to find the closest:

- a) Wind turbine
- b) Coal power plant
- c) Nuclear power plant
- d) Hydroelectric power plant

1004. Use the site https://www.fingrid.fi/en/electricity-market/power-system/ to study current production and use of electricity in Finland. How much is being used, produced and imported at the moment?