fysics on five sheets (doublesided)

Ingredients of → large scale world	Time	Space	Matter	Charge
	(t)	distance (d), height (h), displacement ($\vec{x}$), etc.	mass (m)	(q)
mks units →	seconds (s)	meters (m)	kilograms (kg)	coulombs (C)

All Other Quantities Are Based on These Fundamental Ones

	Name	Definition	Units	Others w/ Same Units, etc.
	Motion			
1	Velocity ($\vec{v}$)	$\vec{v} = \triangle\vec{x}/\triangle t$	m/s	Initial/Final velocity, $\triangle\vec{v}$, speed= $\frac{\triangle d}{\triangle t}$
2	Momentum ($\vec{p}$)	$\vec{p} = m \cdot \vec{v}$	kg·m/s	
3	Acceleration ($\vec{a}$)	$\vec{a} = \triangle\vec{v}/\triangle t$	m/s^2	
∗ 4	Force ($\vec{F}$)	$\vec{F} = m \cdot \vec{a}$	Newtons (N)	
∗ 5 ∗ 6 ∗ 7	Kinetic energy (KE) Grav. potential energy (PE) Work (W)	$KE = \frac{1}{2}m \cdot v^2$ $PE = m \cdot g \cdot \triangle h$ $W = F \cdot d$	} Joules (J)	Heat (Q) (acceleration of gravity, $g \approx 10 m/s^2$)
∗ 8	Power (P)	$P = \triangle W/\triangle t \quad (\frac{\triangle work}{\triangle time})$	Watts (W)	$\triangle(\text{Energy})/\triangle t \quad P_{electrical} = I \cdot V$
	Waves			
9	Wavelength (λ)	cycle-length	Meters (m)	All lengths, heights, displacements
∗ 10	Frequency (f)	f = wavespeed/λ	Hertz (Hz)	(electromag wavespeed, $c = 3.00 \times 10^8$ m/s)
11	Period (T)	$T = 1/f$	Seconds (s)	All time measurements
	Heat			
∗ 12	Heat (Q)	Internal energy (roughly)	Joules (J)	All energies, work
13	Specific heat (c)	$c = Q/(m \cdot \triangle T)$	$J/(kg \cdot {}^\circ C)$	
∗ 14	Temperature (T)	Related to internal energy	°C	
	Electricity			
∗ 15	Current (I)	$I = \triangle q/\triangle t$	Amperes (A)	
∗ 16	Voltage (V)	V = Energy/Charge	Volts (V)	(Note Power above: $P_{electrical} = I \cdot V$)
∗ 17	Resistance (R)	$R = V/I$ or $V = I \cdot R$	Ohms (Ω)	

Notes: 1) Starred quantities have special names for their units; e.g., force is expressed in N, not usually $kg \cdot m/s^2$; it follows that $1N = 1kg \cdot m/s^2$, $1J = 1N \cdot m$, 1W(watt) = 1J/s, etc.

2) If z is any variable, the change $\triangle z = z_{final} - z_{initial}$ is always measured in the same units as z.

3) The definitions of velocity, acceleration, etc., are strictly speaking for their averages.

4) Other units may be used: distances may be measured in feet, cm, etc., time in hours minutes, etc.

5) Some symbols have multiple uses: "T" stands for temperature; "T" for period;
"C" is the unit of charge (coulomb) or the unit of temperature (°C), depending on context;
"m" stands for mass in formulas such as $F = m\,a$, and for meters in units (e.g., 20 m/s);
"W" stands for work in formulas , and for watts in units (see the line for Power for both uses).

6) The concepts of temperature and heat are complicated and cannot easily be defined by formulas.

Laws of Nature

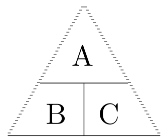
Gravitation: $F = G\frac{m_1 m_2}{d^2}$, $G = 6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$ Gravitational constant

Electricity: $F = k\frac{q_1 q_2}{d^2}$, $k = 8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$ Coulomb constant

A Few Explanations

(Equation numbers in parentheses refer to equations on the definitions page)

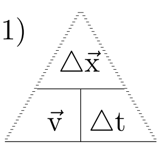
Always Use Units – Consistently

We will use diagrams such as 

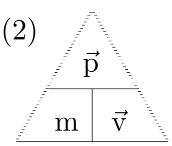
to represent the three equivalent formulas A = BC, B = A/C, and C = A/B. The diagram tells you how to calculate one of A, B, or C, if you know the other two. It also tells you, for example, that from the information in this formula, A depends only on B and C, not on anything else. This will be discussed below when we get to force and to energy.

Motion

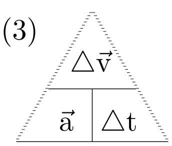
Fundamental quantities: **distance** (or **displacement** or **height**), **time**, **mass**.
Basic quantities: **velocity** (or **speed**), **momentum**, **acceleration**, **force**.

(1) 

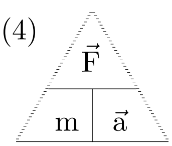
velocity= disp./time

(2) 

Momentum= mass×velocity

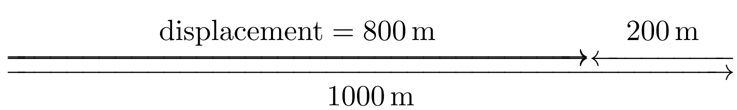
(3) 

Accel.= vel./time

(4) 

Force= mass×accel.

Given two quantities in any of these formulas, you can calculate the third. If the quantities are vectors, then the magnitude (numerical size) and the direction must be stated. Statements about scalars (e.g. speed) need only specify the magnitude. Displacement, velocity, acceleration, momentum, and force are vectors (there's a little arrow on the top to indicate this); all other quantities on page 1 are scalars. "Displacement" and "distance" are used differently; the first is considered a vector and the second a scalar. If you travel to the 1000 m to the right, then back 200 m to the left, you have traveled a total distance ($\triangle$d) of 1200 m, but your net displacement ($\triangle\vec{x}$) is only 800 m:



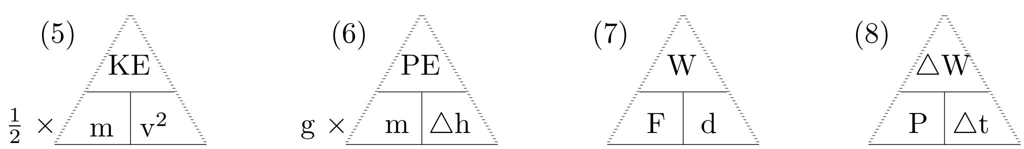
If the trip took 10 s, then your average speed ($\triangle d/\triangle t$) was 1200/10 = 120 m/s, whereas your average velocity ($\triangle\vec{x}/\triangle t$) was 800/10 = 80 m/s to the right.

Velocities, speeds, and accelerations do not depend on the mass. You use the definitions of velocity and acceleration to calculate distances, heights, etc., given velocities and accelerations, or to get velocities and speeds, given distnaces and so forth. (See the "minor note" at the end of this section.)

Momentum depnds only on mass and velocity, not on acceleration. Without external forces acting on it, the total momentum of a system cannot change (**conservation of momentum**). This is a very important principle. It can be used to solve many problems where the initial velocities and masses are known, and you have to calculate the final velocities. For example, suppose two moving objects collide and join. If you know their masses (m_1 and m_2) and their initial velocities ($\vec{v}_1$ and $\vec{v}_2$), you can calculate the total initial momentum ($m_1\vec{v}_1 + m_2\vec{v}_2$). If no external forces act on the system, this will be the same as the final momentum. Therefore, if you divide this momentum by the total mass ($m_1 + m_2$), you get the final velocity of the combined system. You can also use the principle to deduce what some of the initial velocities must have been, if you know the masses and final velocities. The principle tells you that if part of a system with no external forces on it moves one way, the rest of it must move in the opposite direction. This is rocket science.

Force causes acceleration. Force depends only on mass and acceleration, not on velocity; two different systems may have the same velocities at an instant, but may have very different forces acting on them. If all forces balance on a stationary system, it will stay stationary. If the system is already moving, it will keep moving at the same velocity. Forces are not needed to maintain steady motion, but an *unbalanced* force is needed in order to start motion.

Very important additional quantities: **energy/work**, **power**.



Kinetic energy $= \frac{1}{2}$ mass×vel^2 — Pot. energy (grav) =mass×g×height — Work= force×distance — Power= work/time

Energy comes in many flavors. The two shown here come from motion (KE) and position under a gravitational force (grav. PE). The $\frac{1}{2}$ and the g near the first two triangles are to remind you that the formulas are $KE = (\mathbf{1/2}) \cdot m \cdot v^2$ and $PE = m \cdot \mathbf{g} \cdot \triangle h$. If you have to calculate PE, you must multiply g with the product of m and $\triangle h$ in order to get the answer. If KE and v^2 are given, you must multiply v^2 by $\frac{1}{2}$ before you divide into KE in order to get the mass. Both KE and PE depend on the mass. If the mass doubles, each form of energy also doubles (if everything else stays the same). PE also depends on height. If the height doubles, the PE also doubles. KE depends on the *square* of the speed. If the velocity doubles, the KE goes up by a factor of $2^2 = 4$. The triangle diagrams show you that KE depends only on the speed^2 and mass, not on position; PE depends on the height (or the gap in height) and the mass, but not on speed. Two objects with the same mass and at the same height moving with different speeds will have different values of KE, but the same PE. PE also depends on g, the acceleration due to gravity. On Earth that's about $10\,m/s^2$. On planets with a different gravitational pull the value is different.

Work ($W = F \cdot d$) has the same units as energy. If you exert a force, F, on a system and move it (or part of it) through a distance d, you have performed work given by $F \cdot d$. The energy of the system changes by exactly this amount. Sometimes the terms "work" and "energy" are used interchangeably. If no movement occurs ($d = 0$), then no work has been performed, even if that's sometimes against intuition. As a quantity in physics, if you make a big effort to push something and fail to move it, you have done no mechanical work on it (however exhausted you may feel). If no external work is done on a system (roughly, no forces act on it), then its *total* energy cannot change. PE may change to KE within the system, or KE to PE, but the total remains fixed. This is the important principle of **conservation of energy**. A bouncing ball, or anything moving up and down (in addition to possibly moving sideways), is a good example of the exchange of potential and kinetic energies. At the top, the ball is at rest for an instant (zero velocity), so has no KE but the maximum possible PE. At the bottom, it has maximum KE and no PE. If you know the mass, and the ball starts at rest (therefore no KE), then drops through a height, $\triangle h$, you can calculate the decrease in gravitational PE (calculate $m \cdot g \cdot \triangle h$), set it equal to $\frac{1}{2}mv^2$ (KE), and calculate the velocity.

In practical situations it appears that energy sometimes vanishes. An object that's given an initial push on a table top will slide for a bit, then stop. The KE it had in motion is not lost, but is dissipated due to the frictional forces between it and the table.

Power ($P = \triangle W / \triangle t$) is the rate at which work is done, or energy gained or lost. You may do the same amount of work in two instances, or give up the same amount of energy, but the quicker process has greater power. Observe that the work done depends only on force and distance and not on the time taken, but the power depends on the time.

Newton's Law of Gravitational Force

$$F = G\frac{m_1 m_2}{d^2}, \qquad G = 6.67 \times 10^{-11}\frac{N \cdot m^2}{kg^2}$$

Gravitational constant

This is one of two basic laws that tell you how forces *arise* (an equation such as $F = ma$ tells you the effects of a force – it causes acceleration – but not what causes the force). The other law is for electrical forces. This law tells you that the gravitational force between two objects with masses m_1 and m_2 is always attractive and points in the direction of the straight line between them.

$$m_1 \ \bigcirc\!\!\rightarrow \ \underbrace{\text{Attractive gravitational force}}_{\text{distance} = d} \ \leftarrow\!\!\bigcirc \ m_2$$

If the masses go up, the gravitational force goes up. If the distance between the two objects goes up, the force goes *down by the square of the distance*. If the distance becomes 2 times as big, the force goes down by a factor 4; if the distance becomes 3 times as big, the force goes down by a factor of 9. Going in the opposite direction, if Earth halves its distance to the sun, we will feel a gravitational force from the sun that's 4 times as big. This means that if the distance between two objects doubles, one of their masses would have to go up by a factor of 4 in order to keep the force the same.

Gravitation makes the world go round. It's what makes the planets revolve around the sun the way they do, and the moon revolve around the earth.

Note: The formulas from the opening page, (1) $\vec{v} = \triangle\vec{x}/\triangle t$ and (3) $\vec{a} = \triangle\vec{v}/\triangle t$, can be rewritten in many ways using $\triangle\vec{v} = \vec{v}_f - \vec{v}_i$ and $\vec{v}_{average} = (\vec{v}_i + \vec{v}_f)/2$ (where $\vec{v}_i = \vec{v}_{initial}$ and $\vec{v}_f = \vec{v}_{final}$). So we have $\vec{v}_f - \vec{v}_i = \triangle\vec{v} = \vec{a}\cdot\triangle t$ from (3). Or

$$\boxed{\vec{v}_f = \vec{v}_i + \vec{a}\triangle t}$$

With a bit more work, the two formulas below also follow from the basic definitions:

$$\boxed{\triangle\vec{x} = \vec{v}_i\triangle t + \tfrac{1}{2}\vec{a}\triangle t^2}$$

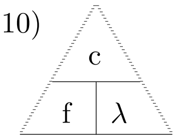
$$\boxed{v_f^2 = v_i^2 + 2a\triangle x}$$

You use one of these boxed formulas depending on what you're given and what you're asked for. If asked for $\vec{v}_f$ and given $\vec{v}_i$, $\vec{a}$ and $\triangle t$, use the first boxed equation. If asked for $\vec{v}_f$ and given $\vec{v}_i$, $\vec{a}$ and $\triangle\vec{x}$, use the third.

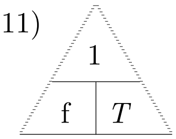
Waves

Basic quantities: **wavelength**, **frequency**, **wavespeed**, **period**.

Wavelength is the length of a wave. It can be measured from one peak to the next. The **frequency** is the number of cycles (or waves) that pass in one second. The **wavespeed** is the speed of the waves. The basic equation here is (10): $f = \text{wavespeed}/\lambda$. Given two of the three quantities, wavespeed, f, and λ, you can find the third. The **period** T of a wave is the time taken for one wave cycle to pass. Therefore $T = 1/f$. If the speed is c (speed of electromagnetic radiation in vacuum, 3×10^8m/s), you can capture the two basic formulas (the formulas can be used for any speed, not just c) as:

(10) 

wavespeed=
feq.×wvlngth

(11) 

period=
1/freq.

For a fixed wavespeed a longer wavelength means a lower frequency, and a shorter wavelength means a higher frequency. If you know the wavespeed you can use the equations of motion from above to find the distance waves travel in a given time, etc. Higher frequency waves deliver more energy. That's why long exposure to high-frequency (and low wavelength) radiation such as x-rays can be damaging.

Electromagnetic Spectrum

high ⟵ frequency, f (and energy) ⟵ low

gamma x-rays ultraviolet visible infrared microwaves radio

V I B G Y O R

short ⟶ wavelength, λ ⟶ long

When waves traveling in one substance hit the boundary with another, part or all of them might bounce back. This is called **reflection**. The angle that the reflected waves make with a line perpendicular to the boundary (the "normal") is the same as the angle made by the original waves. Some may pass through to the other substance, with a bend in the path if they travel at a different speed in the second substance. This phenomenon is called **refraction**. If the speed in the second substance is slower than the first they bend toward the normal; if it is faster they bend away.

Waves come in two varieties: longitudinal (vibrations in the direction of motion; e.g., sound waves in air or water, or waves transmitted along the length of a spring), and transverse (vibrations at right angles to motion; e.g., electromagnetic waves/radiation, water waves, or waves on a string/spring that's moved up and down). Sound waves in metals are transmitted longitudinally, but there's also transverse part. The **amplitude** of a transverse wave is the maximum height achieved by a wave crest from it's undisturbed position. It is measured at right angles from the direction of motion. All kinds of waves transmit energy, but the material that's vibrating (air, water, string) only moves back and forth, and does not move with the wave. Of all common examples of waves, electromagnetic waves have the astonishing property that they can travel through a vacuum – they do not need a physical medium, unlike sound waves (molecules of air vibrate back and forth), water waves (molecules of water vibrate up and down), etc. The discovery that this is true was our first hint that the "physical world" is made up of more abstract ingredients than we first thought.

The speed of electromagnetic radiation in a vacuum, c, is the fastest speed allowed by the law (of nature).

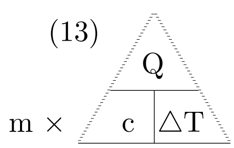
Heat

Basic quantities: **heat**, **temperature**, **specific heat**.

Heat (Q) is roughly a measure of the internal energy of a system and **temperature** (T) of the average kinetic energy of the molecules. Heat, being a form of energy, is measured in energy units (Joules). Adding heat increases the energy of molecules (they move faster, in general, and their kinetic energy goes up) and it increases the temperature. For two systems of the same type, the one at higher temperature will have more energetic molecules (they'll be zipping around faster). Adding heat also generally leads to expansion. The tires of a car, for example, must be inflated slightly less in the summer than in the winter, because the air in them will expand a bit in the summer. Heat flows from higher to lower temperatures. Two objects at different temperatures when placed in contact with each other will both settle to the same final temperature (this is called thermal equilibrium), somewhere between the two initial temperatures.

The **specific heat** (or "specific heat capacity") of a substance is the amount of heat you need in order to increase the temperature of one mass unit (one kg) of the substance by one degree. A higher specific heat means that you need more heat to make the temperature go up by the same amount. The formula is (13) $c = Q/(m \cdot \triangle T)$, or equivalently $Q = c \cdot m \cdot \triangle T$:

(13)



specific heat=
heat/(mass×temp)

If you know the specific heat and mass the formula tells you how to calculate the temperature change from the heat added or removed. If the same amount of heat is supplied to two objects of the same mass but different specific heats, the one with higher specific heat will undergo a *smaller* temperature change. Similarly, if heat is supplied to two objects of the same specific heat but different masses, the one with a higher mass will undergo a *smaller* temperature change. In both cases, you get the final temperature by adding the temperature change to the initial temperature.

Heat is transferred in three ways: **conduction** (think of a hot object touching you), **convection** (think of warm air circulating), and **radiation** (think of the direct warmth of the sun on your skin, beyond hot air). If you hold a metal rod at one end and there's a small explosion of heat at the other end, you'll feel the heat from the explosion in three ways: the direct heat will reach you by radiation; the heat will be transmitted along the rod by conduction; and the molecules of air will pick up energy from the explosion, circulate and distribute the energy to molecules near you by convection. Conduction requires direct contact; radiation abhors it.

Fundamental quantity: **charge**.
Basic quantities: **current**, **voltage**, **resistance**, **electrical power**.

(17)

Ohm's Law
volt.=curr.×res.

electric power=
curr.×volt.

Current is the rate of flow of **charge**, but at this level you don't have to worry about the definitions of current (or voltage). Ohm's law allows you to calculate one of V, I and R, if you know the other two. It tells you, for example, that as the voltage goes up across a fixed resistance, the current goes up in proportion (if the voltage doubles, the current doubles; if the voltage triples the current triples). The second formula allows you to calculate one of P, I and V, from the other two. These concepts are useful in understanding electrical circuits. SERIES AND PARALLEL

Charge is a fundamental property of matter, just as mass is. Unlike mass, charge comes in positive and negative varieties. The law of gravitation says that "like masses" (the only kind we know) always attract each other. The law of electric forces (below) says that the force between "like charges" (both positive or both negative) is repulsive, and between "unlike charges" (one positive, the other negative) is attractive. All substances are built out of units called atoms. The internal components of atoms include electrons (negative charge), protons (positive charge), and neutrons (negative charges). Electric current is the flow of electrons in an electrical conductor; static electricity arises from a transfer of electrons. In both cases the protons and neutrons stay put.

Coulomb's Law of Electrical Force

$$F = k\frac{q_1 q_2}{d^2}, \qquad \underbrace{k = 8.99 \times 10^9}_{\text{Coulomb constant}} \frac{N \cdot m^2}{C^2}$$

This is one of two basic laws that tell you how forces *arise* (an equation such as F = ma tells you the effects of a force – it causes acceleration – but not what creates it). The other law is for gravitational forces. This law tells you that the electrical force between two objects with charges q_1 and q_2 is repulsive if they are both positive or both negative, and attractive otherwise.

$$+q_1 \quad \underbrace{\bigcirc\!\rightarrow \quad \text{Attractive electrical force (unlike charges)} \quad \leftarrow\!\bigcirc}_{\text{distance} = d} \quad -q_2$$

$$-q_1 \ \bigcirc\!\leftarrow \underbrace{\text{ Repulsive electrical force \quad (like charges) }}_{\text{distance} = d} \rightarrow\!\bigcirc \ -q_2$$

$$+q_1 \ \bigcirc\!\leftarrow \underbrace{\text{ Repulsive electrical force \quad (like charges) }}_{\text{distance} = d} \rightarrow\!\bigcirc \ +q_2$$

If the charges go up, the gravitational force goes up. If the distance between the two objects goes up, the force goes down *by the square of the distance.* If the distance becomes 2 times as big, the force goes down by a factor 4; if the distance becomes 3 times as big, the force goes down by a factor of 9.

Common sense physics

Feeling hot and cold (touch, etc.): Things feel cold because they conduct heat away from you.

Friction: moving and static: It takes more effort to start something moving, than to keep it moving.

Doppler effect: Higher frequency as source approaches (more waves reach you per second), lower as it recedes.

Conduction: Metals conduct better than rubber, wood, glass, etc. Electrons move more freely.

Falling bodies: All objects fall under gravity at the same rate, neglecting air resistance.

Weight vs. Mass: Your weight on Earth results from the force of gravity between your mass and the mass of Earth. It's a force, and is measured in Newtons.

Sound: Sound waves travel faster in water than air, and even faster in metals such as steel.

Electricity: Generated by magnets moving near coils.

Harmonic motion: Certain types of back-and-forth motion such as a pendulum swinging, or an object moving up and down when attached to a spring. Systems that exhibit this kind of motion are lumped together under the umbrella term "harmonic oscillators."

Two-stepping: Some problems have two steps (and some might have a hundred or more). You might have two circuits with identical batteries to study, and you might have to use the first to get V (given R and I for that circuit), then use this V to learn something about the second circuit.

Comparisons: You can often compare systems of the same type without having full information. If you have two systems of the same mass, the one that experiences a greater force will accelerate more. You can conclude this without knowing the mass of the systems, even though you cannot calculate the precise acceleration. Similarly, the responses of two samples of the same specific heat to heat added can be compared without knowing what the specific heat is, as long as you know their masses.

A=B×C: There are many equations in physics with this structure. Several aspects of their behavior can be understood in a unified way. Some of the equations are

$$\vec{p} = m \times \vec{v} \qquad \vec{F} = m \times \vec{a} \qquad W = F \times d \qquad c = f \times \lambda \qquad V = I \times R \qquad P = I \times V$$

In all of these if A is fixed (the left hand side), then as B goes up, C must go down (or as B goes down, C goes up). For waves traveling at a fixed speed, for example, as f goes up, λ must go down. For a circuit to which you apply a fixed voltage (V), as the resistance (R) goes down, the current (I) goes up.

If one of B or C is fixed, say B, then as A goes up, C also goes up. For a fixed mass, increasing the force will increase the acceleration. If you plot A against C on a graph, the slope will give you the value of B.