# 6.2 Thermal Physics

## 6.2.1 Thermal Energy Transfer

Internal energy is the sum of the kinetic energies and potential energies of all the particles in a gas.

Potential energy comes from the interactions between the particles.

The internal energy can be increased by adding energy to the system (e.g. by heating it).

#### Specific Heat Capacity

The specific heat capacity of a material is the amount of energy needed to raise one kilogram of material by 1 degree Kelvin.

$$Q = mc\Delta\theta$$

Where $Q$ is the energy required, $m$ is the mass, $c$ is the specific heat capacity and $\Delta\theta$ is the change in temperature.

Temperature calculations should always be done in Kelvin (no funny business with negatives).

#### Specific Latent Heat

Specific latent heat is the energy required to change the state of an object.

To make an object go from a solid to a liquid or a liquid to a gas you need to add some energy. This energy goes into weakening the intermolecular bonds NOT into changing the temperature. The equation for this is:

$$Q = ml$$

Where $Q$ is the energy needed, $m$ is the mass and $l$ is the specific latent heat.

#### Thermal Energy Transfer Experiments

There are 2 ways heat transfer changes materials, by changing the temperature of an object or changing the state of the object. ![[simple-specific-heat-capacity-experiment.png]] The experiment above is a simple way of calculating the specific heat capacity of a material (the black shape) by heating it and measuring the temperature with the temperature probe.

You need to ensure that the heater is fully surrounded by the material and that you record the mass of the material before placing the heating element inside it. Make sure that there is an ammeter and voltmeter

The thermometer records the original temperature and then the temperature after every minute once the heating starts.

Then you can plot a temperature-time graph. Since the gradient is $\frac{\Delta\theta}{t}$ then when put into the equation for specific heat capacity it gives:

$$\frac{Q}{t} = mc \times \frac{\Delta\theta}{t}$$

And since $\frac{Q}{t}$ is power and we know the current of the circuit and voltage across the heater we can right it as:

$$IV = mc \times gradient$$

And solving for $c$ gives:

$$c = \frac{IV}{m \times gradient}$$

There are some issues with this method though, being that the heating affect is assumed to be constant throughout (it is not) and ignores any heating done to the rest of the room.

### 6.2.2 Ideal Gases

**Kelvin Scale**

The Kelvin scale is similar to the Celsius scale except instead of 0$^{\text{o}}$ being the melting point of water, 0K is absolute zero, the lowest temperature possible.

At absolute zero, particles have no energy, they have 0 kinetic energy and they do not vibrate.

Converting from Celsius to Kelvin is easy as:

$$0^{\text{o}}\text{C} = 273.15\text{K}$$

So its as simple as adding 273.15 when converting from Celsius to Kelvin and subtracting 273.15 when converting from Kelvin to Celsius.

**Ideal Gas Law**

$$pV = nRT$$

Where $p$ is the pressure of the gas, $V$ is the volume of the gas, $n$ is the number of moles, $R$ is the ideal gas constant (8.31) and $T$ is the temperature.

There is another equation relating to the one above which is:

$$Rn = kN$$

Where $R$ is the ideal gas constant, $n$ is the number of moles, $k$ is the Boltzmann constant and $N$ is the number of molecules.

Avogadro's constant is given by the equation:

$$N_a = \frac{R}{k}$$

Where $N_a$ is Avogadro's constant, $R$ is the ideal gas constant and $k$ is the Boltzmann constant.

Using this we can now write the ideal gas equation in the form:

$$pV = NkT$$

Where $p$ is the pressure of the gas, $V$ is the volume of the gas, $N$ is the number of molecules, $k$ is the Boltzmann constant and $T$ is temperature.

### Work Done on an Ideal Gas

You can find the work done on an object by multiplying the average force by the displacement of the object moved in the direction of the force.

Pressure is just force divided by the cross-sectional area the force is acting on. This means you can substitute it into the equation for work done, giving you the equation:

$$W = pA\Delta x$$

Where $W$ is the work done, $p$ is the pressure, $A$ is the cross-sectional area and $\Delta x$ is the distance travelled. This can be simplified to:

$$W = p\Delta V$$

Where $\Delta V$ is the change in volume of the gas.

Both these equations assume that the pressure is constant.

**Molecular Mass**

Avogadro's constant, $N_a$ is the number of particles in 1 mole of any given substance.

$$\text{mass} = \text{relative molecular mass} \times \text{no. of moles}$$

**Gas Laws**

**Boyle's Law**
Boyle's law describes the relationship between the pressure and volume of a fixed mass of gas at constant temperature.

$$P \propto \frac{1}{V}$$

Meaning that pressure is inversely proportional to the volume of a gas. This could also be written as $PV = k$ where $k$ is some constant. This form is more useful as you can now compare the same gas when it has 2 different volume and pressures but the same temperature. The equation is:

$$P_1V_1 = P_2V_2$$

**Charles' Law**
Charles' law describes the relationship between the volume and temperature of a gas.

$$V \propto T$$

Meaning that volume is proportional to the temperature of a gas. It could also be written in the form $\frac{V}{T} = k$ where $k$ is some constant. This form is more useful as you can now compare the same gas when it has 2 different volumes and temperatures but the same pressure. The equation is:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

### 6.2.3 Molecular kinetic theory model

Assumptions of the molecular kinetic theory model: - No intermolecular forces - Random motion of particles (Brownian motion) - Molecules move in a straight line - Molecules follow Newton's laws of motion - Duration of collisions is negligible relative to the time between collisions

**Brownian Motion**

Brownian motion is the erratic random movement of microscopic particles in a fluid. This was first noticed by Robert Brown when he saw the movement of pollen grains suspended in still water.

**Average molecular kinetic energy**

We assume that the gas is homogeneous (the same everywhere) and isotropic (has the same value when measured in different directions). This means that the average speed of a molecule in the x-direction must be the same as the y and the z-directions. So we can write:

$$v_x = v_y = v_z$$

Which means that the average kinetic energy is the same in every direction.

# 7.2 Gravitational Fields

Equations for this topic:

| | Over $r^2$ | Over $r$ |
|---|---|---|
| Has 2 masses | $F = \frac{Gm_1m_2}{r^2}$ | $W = \frac{Gm_1m_2}{r}$ |
| Has 1 mass | $g = \frac{Gm_1}{r^2}$ | $V = \frac{Gm_1}{r}$ |

$F$ is force, $W$ is work done, $g$ is gravitational field strength and $V$ is potential.

## 7.2.1 Newton's Laws

$$F = \frac{Gm_1m_2}{r^2}$$

## 7.2.2 Gravitational Field Strength

Gravitational field lines around a point mass or spherical mass are radial and point towards the mass (since gravity is always attractive).

The field lines indicate the direction an object would experience a force in if it were near the point/spherical mass.

Close to the surface of the Earth and over small distances, the field lines seem to be equally spaced and parallel. This is why in our everyday experience we think of the Earth's gravitational field is uniform.

Gravitational field strength is defined by the relationship:

$$g = \frac{F}{m}$$

### 7.2.3 Gravitational Potential

Gravitational potential is defined as the work done per unit mass - its unit is $Jkg^{-1}$. It is the work done that would have to be done to a unit mass to take the mass to a defined zero point (basically you multiply it by the mass and you get the energy needed to move it to the defined point of zero potential (infinity)).

The zero value of gravitational potential is defined as being an infinite distance away from the mass generating the field, this is done so that when a small test mass is placed in the gravitational field, the test mass has work done on it by the original mass and gains kinetic energy, to gain that kinetic energy the object must have lost gravitational potential energy, in other words the gravitational potential has become more negative.

If an object moves parallel to equipotential lines (field lines where a point anywhere along them has the same potential) then its potential does not change.

### 7.2.4 Orbits of Planets & Satellites

When an object orbits a more massive object it has a set period and radius which depend on each other. They have the following relationship:

$$T^2 \propto r^3$$

This is Kepler's third law.

#### Energies of Orbiting Objects

In a circular orbit, the satellite is always on the same equipotential and so the total energy of an orbiting satellite is constant. - The planet does no work on the satellite, so there is no loss in potential and no loss in gravitation potential energy - The radius of the orbit does not change - The kinetic energy of the satellite does not change and so it has a constant speed.

In non-circular orbits (ellipses or parabolas) we can show that the total energy of an orbiting satellite is always equal to half the gravitational potential energy of the satellite. This is because gravitational field strength follows an inverse-square law.

### 7.2.5 Escape Velocity and Synchronous Orbits

Escape velocity is the velocity needed for an object to escape a planet's gravitational pull.

The escape velocity, $v_e$ can be estimated by equating the equations for kinetic energy and gravitational potential energy.

$$\frac{1}{2}m{v_e}^2 = \frac{GMm}{r}$$

Where $m$ is the mass of the object you want to leave the planet, $M$ is the mass of the planet and $r$ is the radius of the planet.

This equation can be rearranged to solve for $v_e$ which gives:

$$v_e = \sqrt{\frac{2GM}{r}}$$

**Synchronous Orbits**

**Geosynchronous orbit** − a satellite in geosynchronous orbit remains at the same point above the Earth at all times. The satellites can be used for weather mapping and observation as they can watch the same place for long periods of time.

**Geostationary orbit** − a satellite in geostationary orbit is a geosynchronous satellite except that it is above the equator.

Geosynchronous orbits have a time period of exactly 1 day, this can be used to calculate the radius of the orbit:

$$r^3 = \frac{GMmT^2}{4\pi^2}$$

## 7.3 Electric Fields

### 7.3.1 Coulomb's Law

Coulomb's law is very similar to Newton's law of gravity except it can both repel and attract objects depending on their charges. The equation for it is:

$$F = \frac{1}{4\pi\epsilon_0} \times \frac{Q_1 Q_2}{r^2}$$

Where $\epsilon_0$ is the permittivity of free space (the ability of electrical fields to pass through a classical vacuum).

The Electromagnetic force is far stronger than the gravitational force. This suggests that there is another force holding the nucleus of an atom together, which overcomes the electrostatic repulsion between protons. This force is the strong force.

### 7.3.2 Electric Field Strength

The electric field strength is the force per unit charge felt by an object. $E = \frac{F}{Q}$

Using Coulomb's law we can find:

$$E = \frac{1}{4\pi\epsilon_0} \times \frac{Q}{r^2}$$

Electric fields only affect things with charge.

The field lines of electric fields show the direction of the force a positively charged unit charge would experience when placed near the charge. A positive point charge will have radial fields pointing away from its centre and a negative point charge will have radial fields pointing towards its centre.

#### Uniform fields

A uniform field is a field in which the field strength is the same at every point in the field. A uniform field can be made from parallel charged plated. The field between the two plates will be uniform.

If two plates are held apart with different charges they will have a voltage difference between them. The equation for field strength is:

$$E = \frac{V}{d}$$

Where $E$ is the electric field strength, $V$ is the potential difference between the two plates and $d$ is the distance between the plates.

The work done in moving a positively charged particle from the negative plate to the positive plate is $W = F \times d$. Where $F$ is a constant force acting on the charged particle and $d$ is the separation of the plates.

Work done in an electric field is also given by:

$$W = Q \times \Delta V$$

### 7.3.3 Electric Potential

Same basic stuff as gravitational potential.

Given by the equation:

$$V = \frac{1}{4\pi\epsilon_0} \times \frac{Q}{r}$$

### 7.3.4 Capacitance

(not doing this because i have cs to revise for)

## 8.1 Radioactivity

### 8.1.1 Rutherford Scattering

- Fired alpha particles at a very thin piece of gold leaf
- Particles mostly passed through but some were deflected at large angles
- Disproved the plum pudding model

Explanation of results: - The strong deflections were caused by electrostatic repulsion between the positive nucleus and the positively charged alpha particles - Most alpha particles passed through since most of the atom is empty space

### 8.2.2 $\alpha$, $\beta$, $\gamma$ radiation

#### $\alpha$ Particles

- Helium nucleus ($^4_2He$)
- 2 protons and 2 neutrons
- Positively charged
- Weakly penetrating
- Highly ionising
- Emitted by nuclei with atomic number greater than 60.

#### Applications of $\alpha$ radiation

- Fire alarms
  - The alpha particles cannot penetrate through the smoke which is detected by the alarm

#### $\beta$ Particles

- Electron ($e^-/\beta^-$) or positron ($e^+/\beta^+$) emitted from an unstable nucleus
- Positively or negatively charged
- Moderately penetrating
- Less ionising than $\alpha$
- $\beta^-$ particles are emitted by proton rich nuclei
- $\beta^+$ particles are emitted by neutron rich nuclei

#### Applications of $\beta$ radiation

- Can penetrate through 5mm of aluminium
  - Used in the manufacturing of aluminium foil to gauge the thickness of each sheet
- Medical PET scanning

#### $\gamma$ Particles

- Does not change the proton or nucleon number of a nucleus

- Makes the nucleus more stable by its emission
- Highly penetrative
- Can be absorbed by several centimetres of lead, many metres of air and can travel through a vacuum indefinitely
- High-energy photon
- Follows inverse square law
  - intensity = $\frac{\text{constant}}{\text{distance from source}^2}$

**Applications of $\gamma$ radiation**

- Medical imaging
- Cancer treatments
- Sterilising medical equipment
- Irradiate food

### 8.2.3 Radioactive decay

The decay of a radioactive substance is random and spontaneous. To measure decay, we must look at the count rate over a long time to see if it decreases.

The probability that a given nucleus will decay in a given time is proportional to the number of nuclei. The equation for calculating the rate of decay is:

$$-\lambda N = \frac{\Delta N}{\Delta t}$$

Where $\lambda$ is the decay constant, $N$ is the number of nuclei, $\Delta N$ is the change in the number of nuclei, and $\Delta t$ is the change in time.

The reduction in the rate of decay decreases according to an exponential pattern. The exponential relationship is written as:

$$N = N_0 e^{-\lambda t}$$

Where $N_0$ is the initial number of nuclei.

The activity is the rate of decay of nuclei. The activity of a sample can be found by using the decay constant and the number of nuclei. The equation for activity is:

$$A = \lambda N$$

Activity also has an exponential relation ship and is written as:

$$A = A_0 e^{-\lambda t}$$

Half-life ($T_{\frac{1}{2}}$)is the time taken for: - The number of radioactive nuclei in a sample to halve - The activity to halve

The decay constant and half-life are related by the equation:

$$T_{\frac{1}{2}} = \frac{ln(2)}{\lambda}$$

We can calculate how many nuclei are remaining given the activity, atomic mass of the radioactive isotope and the mass of the sample.

Example:

*Find the half-life of a sample of plutonium-239, which has a mass of* $1.2kg$ *and an activity of* $2.8 \times 10^{12} Bq$*.*

- Number of moles of Pu-239 = $\frac{1200}{239} = 5.021$
- Number of nuclei = number of moles $\times$ Avogadro's constant
  - $5.021 \times 6.02 \times 10^{23} = 3.02 \times 10^{24}$
- $\lambda$ = activity $\div$ number of nuclei
  - $\lambda = \frac{2.8 \times 10^{12}}{3.02 \times 10^{24}} = 9.26 \times 10^{-13}$
- So the half-life $T_{\frac{1}{2}} = \frac{ln(2)}{\lambda} = 7.5 \times 10^{11}$ seconds