Physics Revision

Mechanics

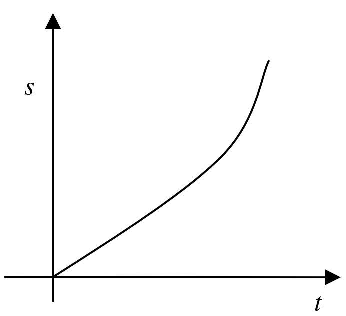
Displacement and Velocity

- Quantities are either vector or scalar. Vector quantities have both a magnitude and a direction, whilst scalars are just numbers without direction. Force, acceleration, velocity and impulse are all vector quantities. While distance is a scalar, *displacement* is a vector since it is the distance moved *in a particular direction*.
- Speed is distance moved per second, and it is scalar since it is calculated with scalar values of time and distance. $speed = \frac{distance}{time}$.
- Velocity is the vector unit of speed, when using velocity you should always state the direction of the movement. Velocity is calculated using $velocity = \frac{displacement}{time}$.
- The average velocity (like the average speed) is the total displacement divided by the total time. If the velocity is changing, then the velocity at any moment is the instantaneous velocity, to find this value you must measure the displacement over a very short period of time.

Acceleration

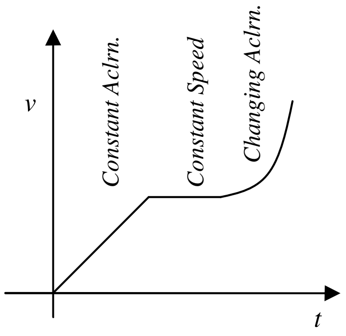
- Acceleration is the change in velocity per second. $a = \frac{\Delta v}{t}$.
- $s = \frac{(u+v)}{2}t$
- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $v^2 = u^2 + 2as$
- When considering objects falling in free-fall, we can substitute a with g where g is a constant for the acceleration due to gravity.

Motion Graphs



Displacement-Time

The gradient at any point is the instantaneous velocity at that given point.



Velocity-Time

The gradient of the graph is the acceleration.

The area under the graph is the displacement during that time.

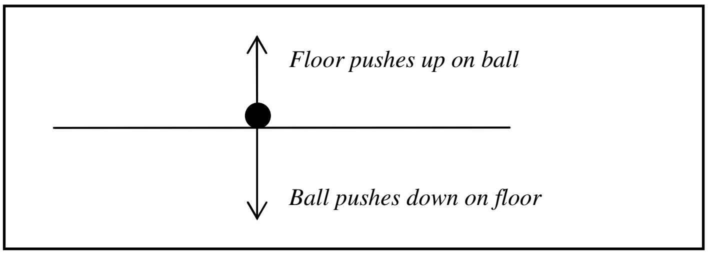
Newtonian Laws

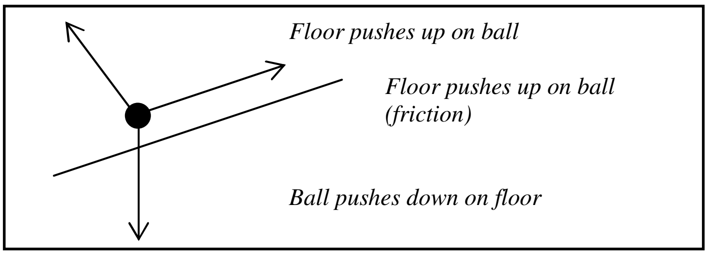
- Newton's First: A body will remain at rest or continue to move with a constant velocity as long as the forces on it are balanced.
  - Inertia is the resistance to change in velocity.
  - So long as forces are in equilibrium there will be no acceleration
- Newton's Second: The acceleration of a body is proportional to its resultant force and takes place in the direction of the force.
  - $F = ma$
- Newton's Third: Objects exert equal and opposite forces upon one another.

Types of Force

- Forces acting at a distance.
  - Gravitational forces
  - Electrostatic forces
  - Electromagnetic forces
  - Nuclear forces
- Contact forces

Free Body Force Diagrams





Moments

- $Moment = F \times PerpendicularDirection$
- Torque is the turning moment caused by a system of two or more forces. Moments do not cause translational movement (acceleration) but they rotate.
- When an object is not turning it is in rotational equilibrium and the sum of the moments at any point is 0.

Momentum

- $Momentum, p = mv$
- When considering a collision, momentum is conserved. This means that momentum before the collision equals momentum after the collision.
  $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
- In an elastic collision there is no loss of kinetic energy upon collision, in an inelastic collision energy may be used to change the shape of an object, friction, etc.
- $\frac{\Delta p}{t} = F$, Impulse = Change in Momentum, and Impulse = Force × Time.

Work, Energy and Power

- $\Delta W = F\Delta d$, Work is the force times the displacement in the direction of the Force.
- Work is measured in Newton Meters… or Joules. It is therefore a measure of Energy. Energy Transferred = Work Done.
- Power is the rate of doing work. $Power = \frac{work}{time}$.
- Power is measures in Watts. The formula can be derived to get $P = Fv$

Energies

- Gravitational Potential Energy
  - $\Delta W = mg\Delta h$
- Kinetic Energy
  - $\Delta W = \frac{1}{2}mv^2$
- Internal Energy is random kinetic and potential energy of the molecules of a body; this explains where energy lost when falling "goes".
- The principle of conservation of energy is very important, it states that energy can be neither created nor destroyed.
- $Efficiency = \frac{UsefulOutput}{Input}$

Electricity

Charge and Current

- Charge is measured in Coulombs and is the charge on the electrons.
- Current is the rate of flow of charge, an Ampere is a coulomb of charge flowing per second. $I = {}^{\Delta Q}/_{\Delta t}$

Current Control in Circuits

- The current can be controlled in a circuit using various devices or structures.
  - Electrical sensors.
  - A relay circuit where a small current controls a large current.
  - A transistor can control a large circuit with a small circuit by splitting current.

Voltage

- Voltage is the push on the current.
- A difference in voltage (or potential) is what causes electrons to slow down or speed up.
- $E = VQ$, $P = IV$

Kirchoff's Laws

- First: The sum of currents entering a point is equal to the sum of the currents leaving that point.
- Second: Around a closed loop the sum of the emf's is equal to the sum of the pd's. This is from the conservation of energy, $\sum emf + \sum v = 0$.

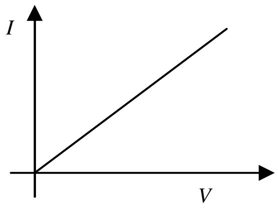
Resistance

- The voltage required to move each amp of current.
- $V = IR$, measured in Ohms
- In series: $R_t = R_1 + R_2$
- In parallel: $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$
- $P = I^2 R$ since $P = IV$ and $V = IR$

Resistivity

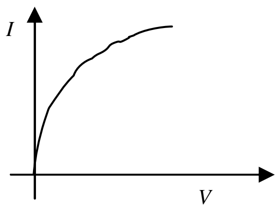
- A measure of an items resistance per unit length.
- $R = \frac{\rho l}{A}$

Resistance Graphs



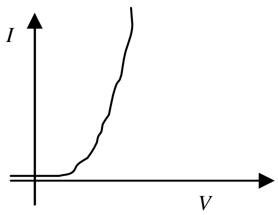
Resistor

A straightforward linear relationship



Filament Lamp

The filament gets hotter and so increases the resistance



Semiconductor Diode

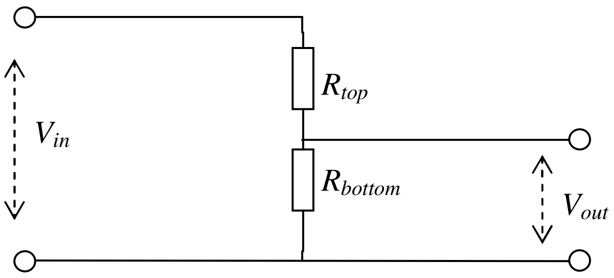
Current may only flow in the one direction.

- Thermistors: As temperature decreases resistance increases since in $I = nAQv$ n is increasing as there are more free electrons.
- LDR's: As intensity increases free electrons increase so resistance decreases.

Drift Speed

- $I = nAqv$ where
  - I = current
  - n = charge carrier density
  - q = charge of an electron
  - v = drift speed
- Current moves very slowly, charge carrier density is higher in metals than semiconductors and insulators.

The Potential Divider



$$V_{out} = V_{in} \frac{R_{bottom}}{\left(R_{top} + R_{bottom}\right)}$$

Voltage Control in Circuits

- By use of the potential divider the voltage output can be controlled
- LDR's and Thermistors can be used in potential dividers to create circuits sensitive to light and heat.

Internal Resistance

- The resistance of a cell
- $E = I(R + r)$

Thermal Physics

Pressure and Temperature

- $p = \frac{F}{A}$
- *pressure* × *volume* = *constant* where temperature is constant.
- *pressure* ÷ *temperature* = *constant* where volume is constant
- Ideal gas equation: $pV = nRT$ from $\frac{pV}{T} = constant$.

Brownian Motion

- Particles are subject to random movement, they dance from one direction to another without pattern.
- This can be observed in smoke particles by observing illuminated smoke particles though a microscope.

Kinetic Theory

- We assume
  - Particles in a gas are in continuous Brownian (random) motion.
  - Molecules never come to a stop and settle
  - Since gases can be compressed a lot, we assume the volume of the particles is negligible compared to the volume of the gas.
  - Therefore particles must be a long way apart, so the only forces acting on them are during collisions.
- From Δ*momentum* on a collision of two particles we can calculate
  - $pV = \frac{1}{3}Nm(c^2)$ or $p = \frac{1}{3}\rho(c^2)$
  - $\frac{1}{2}m(c^2) = \frac{3}{2}kT$ (that temperature is related to a particle's velocity)

Thermal Equilibrium & Steady State

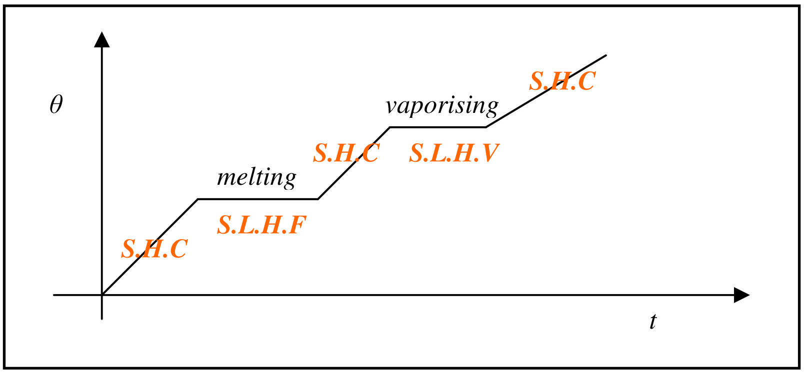
- Placing two objects of different temperatures together they will eventually give their energy to the colder object until both are the same temperature. They are then in thermal equilibrium.
- In steady state there is a constant flow of energy which keeps temperatures constant.

Specific Heat Capacity

- $E = mc\Delta\theta$
- The energy required to produce a unit rise in temperature per unit mass.
- Measured in J kg^{-1} K^{-1}

Specific Latent Heat

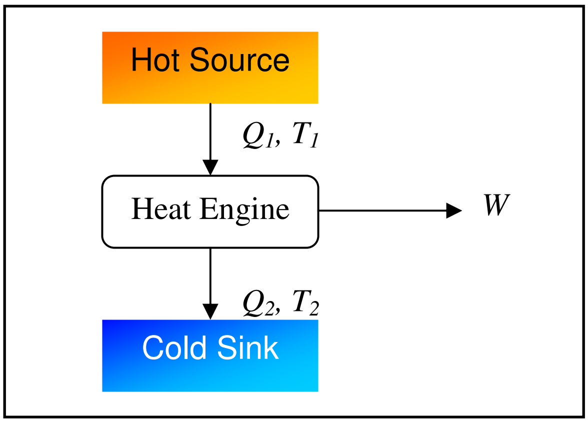
- $E = mL$
- The energy required to turn a unit mass of (solid into liquid)/(liquid into gas) without a rise in temperature.
- Of Fusion or Vapourisation
- The energy supplied is sometimes called the enthalpy.



Internal Energy

- First law of thermodynamics: $\Delta U = \Delta Q + \Delta W$
- Internal energy comprises of energy from kinetic work, and thermal work (heat).

Heat Engines and Pumps

- A heat engine is a device which does work by taking heat energy from a hot body. Examples are power stations.
- 

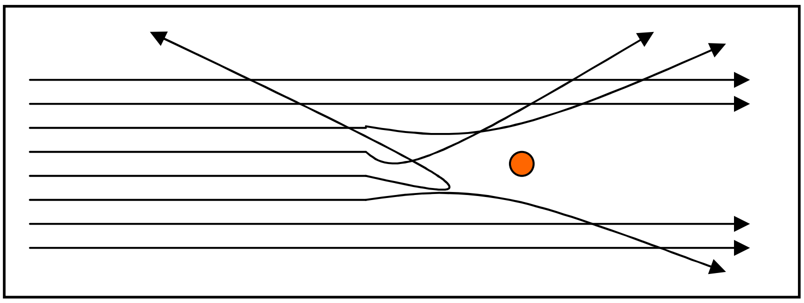
- Energy from hot source = work done + energy given to cold sink
- From $Q_1 = W + Q_2$ we can calculate the efficiency to be $= 1 - \frac{Q_2}{Q_1}$. Since there is always heat loss to the cold sink, a heat engine can never be 100% efficient. The maximum efficiency is $= 1 - \frac{T_2}{T_1}$, and with modern values that's around 57%, and in practice more like 40%.
- A heat pump does the opposite and uses mechanical energy to move heat energy from a cold body to a hot body (i.e. like in a fridge).

Radioactivity

Atoms

- The atomic model:

Particle	*Mass*	*Charge*
Proton	1 u	+ 1
Neutron	1 u	0
Electron	$\frac{1}{8000}$ u	- 1

- Proton number : number of protons in the atom,
- Mass number: number of protons *and* neutrons in the atom,
- Isotope: an version of an element with a different mass number but the same number of protons (i.e. more or less neutrons).
- This model was established and "proved" by Rutherford's scattering experiment. Alpha particles were fired at gold leaf and the path of the alpha particle observed.
- 

  - Some particles pass right though (the atom is small)
  - Some are deflected (there is a positive electromagnetic field)
  - Some rebound off, but very few (a few collide with the actual core which must be massive to cause deflection).

Quarks

- It is believed protons, electrons and neutrons are made up of quarks, which are smaller particles. Evidence for these comes from firing electrons at protons (rather like Rutherford's experiment but on a smaller scale), some electrons are scattered with low energy (a minor deflection) whilst some are suffer high energy scattering.
- These differences mean that the charge in a proton is not uniform.

Radiations

Particle	*Charge*	*Mass*	*Penetration*	*Nature*	*Ionising*
Alpha	+ 2	4 u	5cm / 1mm	Helium nucleus	Heavily
Beta +	+ 1	$\frac{1}{8000}$ u	Annihilated on contact with electron	Positron	-
Beta -	- 1	$\frac{1}{8000}$ u	30cm / 5mm	Electron	Light
Gamma	0	0	Long way	Photon	Single ion pair

Alpha Radiation

- Ionises atoms, giving them sufficient energy to release electrons and potentially carry a current.
- Alpha decay: ${}^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\alpha$

Beta minus Radiation

- In beta minus decay a neutron in the nucleus splits to become a proton and an electron. The electron is fired off at high speed, and the neutron remains in place.
- Beta decay: ${}^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + \left({}^{0}_{1}\text{e}\right)^{-}$

Beta plus Radiation

- Beta plus decay is far rarer in the "real world", but can be stimulated in man made environments. In this decay a proton in the nucleus splits to become a neutron plus a positron. The neutron remains while the positron is ejected at high speed.
- Beta plus decay: ${}^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} + \left({}^{0}_{1}\text{e}\right)^{+}$

Gamma Radiation

- Gamma radiation is a stream of photons which ionise when they react with matter along the way.
- Gamma interacts very little giving it a very long range.

Background Radiation

- There is a naturally occurring amount of radiation, around 2 cps; this is from natural minerals, nuclear weapons testing and cosmic rays.

Rates of Decay

- Radioactive decay is entirely random, when sampled you can see the rate of decay falling exponentially as there are less atoms left to decay.
- Decay can be modelled using the throw a dice.
- The activity, or decays per second, is given by $Activity = \lambda N$, where lambda is the decay constant, and N is the number of nuclei present at that instant.
- Activity is measured in Becquerel (Bq). The decay constant varies for different isotopes.
- Half life is the time taken for half the remaining atoms to decay, this value is roughly constant for each isotope. Half life is connected to the decay constant with the formula $t = \frac{\ln 2}{\lambda}$

Astrophysics

Observing Stars

Optical Telescopes	Types: • Reflector (mirror directs image to small lens) • Refractor (large lens captures image from scope) Problems: • Need to be located high up • Large lenses expensive
Radio Telescopes	A parabolic reflector much like a satellite dish gathers information from many wavelengths.

Detectors

Eye	• Far away images and faint light are lost on the eye • Eye cannot integrate
Photographic Plate / Emulsion / Film	• Different film speeds are relevant, grainy or dimmer… • We end up with a hard copy • Can integrate
Photocathode / Photomultiplier	• Photons hit metal plate knocking out an electron, this carries charge (a domino effect generates a suitable large current to be detected). • Its slow to use, so there is a long "dead time" • Too many photons can damage it
CCD	• Like photographic cells, only they are semi conductor detectors. Each cell can carry a varying amount of charge to build an image where each cell can be a variety of colours. These cells are pixels used to form a digital image. • Quality dependant on pixel size and depth. • Can detect greater range of light • Less "dead time" • Not damaged by light, but may be affected by random noise.

The Atmosphere

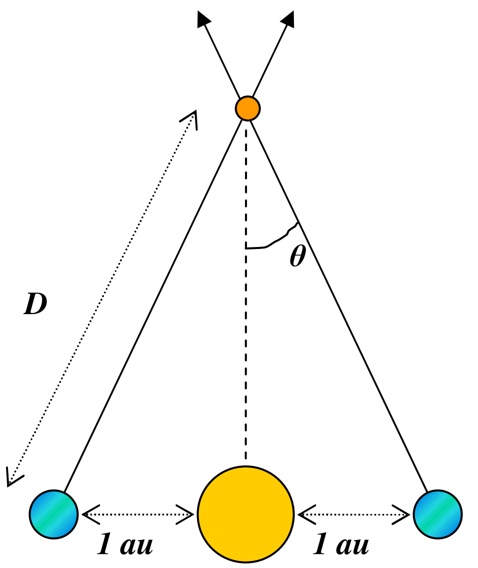
We tend to put telescopes above the atmosphere because light from space is distorted by the atmosphere in a number of ways. The atmosphere absorbs some wavelengths of light, as well as scattering much of the rest. The best places for telescopes are in orbit around Earth, or on the highest peaks of mountains.

Black Bodies

A black body is a "perfect" body which completely absorbs all kinds of em radiation and re-radiates them to maintain thermal equilibrium. It is only a theoretical construct.

Stellar Distances

- The distance to a nearby star can be measured using the stellar parallax. The stars position is recorded against the static background of more distant stars when the Earth is at opposite ends of its orbit. The angle is then measured and the distance calculated via trigonometry.
- This method is only suitable for close stars since otherwise the measured angles are too small to measure accurately. A max distance of about 100 light years is normal.



From small angle approximation, and in radians…

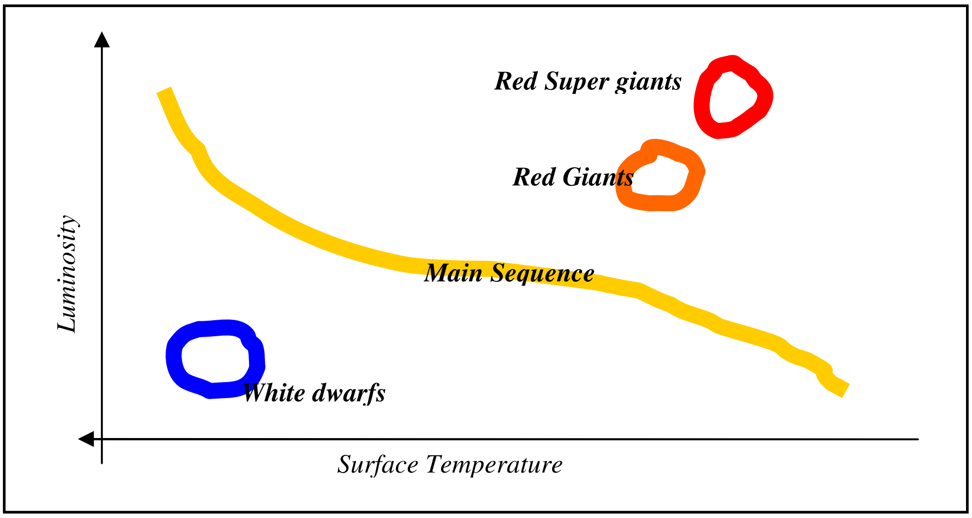
$$D = \frac{1au}{\theta}$$

- Cepheid variables are a kind of star where the brightness of the star varies in a period that depends on its luminosity.
- The period of fluctuation can be measured, allowing calculation of luminosity and thus with measured intensity distance can be found.

Energy from a Star

- Energy from a star is given out at many wavelengths, but there is always a peak wavelength where the relative intensity is highest. This wavelength is called λ_{max}.
- Wein's law links the peak wavelength with the temperature of a star, $\lambda_{\max} = \frac{constant}{T}$, where the constant is 2.898×10^{-3} and T is temperature in Kelvin.
- Wein's law states therefore that the hotter a star the shorter its peak wavelength. We can use Wein's law to estimate the surface temperatures of stars by looking at their dominant wavelengths.
- Stefan's law links the power coming from a star (its luminosity) with its temperature. Luminosity is dependant on surface temperature and surface area. $L = 4\pi r^2 \sigma T^4$.
- As the power radiated spreads out in all directions only a small proportion of it reaches an observer. The intensity of a star is the power per meter squared from it that arrives to the observer.
- Intensity can link the temperature of a star with its distance, D, from Earth, $I = \frac{L}{4\pi D^2}$.

Hertzsprung - Russell diagram



- Stars spend most of their lives in the main sequence, their position rarely changing.
- Stars in the main sequence are hydrogen burning.
- Stars in the same place on the diagram will have the same mass, composition and surface temperature.
- To find the distance from Earth of a distant star, Wein's law is used to find the temperature, (from an observed peak wavelength), then by plotting this on the H-R diagram they can predict the luminosity. The intensity is measured, and all those values substituted into the intensity equation to find D.

The birth of a star

- The molecules of a cloud of gas in space are far apart.
- The force of gravitational attraction pulls these particles together towards the centre.
- Each molecule is falling inwards, gaining acceleration.
- As the cloud collapses the molecules are moving more quickly and colliding more frequently with one another.
- Collisions share kinetic energy, increasing the speed of *all* the particles.
- The faster the molecules move the higher the temperature of the gas.
- The density, temperature and pressure of the cloud are all increasing, while the gpe of the molecules is being converted to kinetic energy.
- The molecules collide frequently and energetically, they eventually form a plasma of fast moving charged nuclei.
- When the temperature is high enough the nuclei can approach one another closely enough that the force of nuclear attraction overcomes the electrostatic repulsion of the particles and fusion begins.

Nuclear Fusion

- The pp chain is the process by which hydrogen fuses to form helium, releasing energy.
- In the pp chain 4 protons become a helium nucleus plus energy.
- The energy comes from a mass difference between four proton and a helium nucleus. This mass difference derives from Einstein's famous equation $E = mc^2$ which links mass to energy. In fusion when 4 protons become a helium nucleus a helium nucleus weighs less than the four protons, therefore the missing amount of mass *becomes* energy.
- To start fusion phenomenal temperatures are required, in a star the temperature doesn't need to be so high because there are so many protons available, to do it on Earth would require much higher temperatures.

Life on the Main Sequence

- All the time in the main sequence stars are burning hydrogen, the kinetic energy produced by this pushes out on the star, expanding it, while at the same time gravity pulls the star back in. These two opposing forces keep the star in a state of equilibrium.
- Larger stars have more gravitational force and therefore particles are pulled in faster (and hotter) meaning they burn their hydrogen quicker and brighter. There live in the top-left of the H-R diagram.
- Smaller stars have a lower gravitational force which means their temperatures are lower and they burn slower, they are in the bottom-right of the H-R diagram.

Post-Main Sequence

- Stars less than 0.4 times the mass of the sun burn their hydrogen very slowly, eventually when the hydrogen is gone gravity pulls the stars in further and they become white dwarfs.
- Stars 0.4-8 times the mass of the sun become red giants. After the hydrogen burning stops, the core contracts raising the temperature sufficiently to allow hydrogen to fuse in a shell around the core, this raises the temperature of the core enough to begin fusion of helium. This pattern continues with stars contracting and expanding as they start to burn new elements in layers around the core. The heat from burning these other elements (Hydrogen → Helium → Carbon → Neon → Oxygen → Silicon → Iron) causes the star to expand considerably. Matter is frequently ejected from the outer layer of the stars. Once as many elements as possible have been fused the death of the giant is the same as that of a smaller star and it cools to become a white dwarf.
- Stars greater than 8 times the mass of the sun follow the same pattern as those slightly smaller – only they become *super* giants. The death of these stars is however different, since they are so massive when they collapse the atoms are compressed so much that electrons in the atoms combine with protons to form neutrons … as the core collapses very quickly this process produces a large amount of energy which blows away the outer layers of the star into space. This shockwave heats up the ejected gas and forms a bright supernova.
    - The remaining core either becomes a neutron star, which are extremely dense objects that emit radiation about their magnetic poles. Pulsars emit pulses of this radiation that is detected by us on Earth.
    - If the core of the super giant is particularly large then the gravitational forces are so great that they pull the entire core into a single point – *singularity*. This is a black hole whose gravitational forces are so huge that even light cannot escape. Black holes are detected by observing them in binary systems, or by X-Rays they emit.