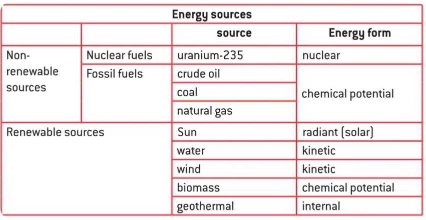
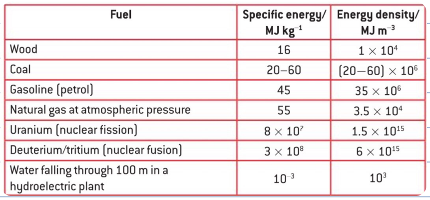
- Energy production
  - 8.1 Energy sources
    - Equations
      - power = $\frac{\text{energy}}{\text{time}}$ - 1kWh = 1000W · 1h (3600s) = 3.6MJ - Mass power delivered = $P = \frac{m}{t} g\Delta h = (\frac{V}{t}\rho) g\Delta h$.
      - Wind power equation = $\frac{1}{2}A\rho v^3$
    - Primary and secondary energy
      - Primary source is a fuel that hasn't been converted before use by consumer.
        - E.g. coal has to be burnt in furnace to convert chemical potential energy to kinetic energy.
      - The secondary source of energy occur due to the transformation of primary sources.
    - Renewable and non-renewable energy sources
      - Renewable resources can be replenished in a short time.
      - Non renewable resources can only be replenished in a very long time.
    - Types of energy sources
      - Primary sources
        -



Energy sources			
		source	Energy form
Non-renewable sources	Nuclear fuels	uranium-235	nuclear
	Fossil fuels	crude oil	chemical potential
		coal	
		natural gas	
Renewable sources		Sun	radiant (solar)
		water	kinetic
		wind	kinetic
		biomass	chemical potential
		geothermal	internal

        - Some energy is always degraded into an internal form in a conversion.
      - Primary energy use
        - Two units which are important:
          - The british thermal unit (BTU). The energy required to raise one British pound of water (0.5kg) through 1°F (≈ Δ0.6K).
            - Its equivalent to about 1000J.
          - Mtoe "millions tonnes of oil equivalent".
            - One tonne of oil equivalent is the energy released when one tonne (1000kg) of crude oil is burnt; roughly 42GJ = $5 \cdot 10^{20}$.
      - Specific energy and energy density
        - Specific energy indicates the number of joules that can be released by each kilogram of fuel.
        - Energy density is the number of joules that can be released from 1m³ of a fuel.
        -



Fuel	Specific energy/ MJ kg^{-1}	Energy density/ MJ m^{-3}
Wood	16	1×10^4
Coal	20–60	$(20-60) \times 10^6$
Gasoline (petrol)	45	35×10^6
Natural gas at atmospheric pressure	55	3.5×10^4
Uranium (nuclear fission)	8×10^7	1.5×10^{15}
Deuterium/tritium (nuclear fusion)	3×10^8	6×10^{15}
Water falling through 100 m in a hydroelectric plant	10^{-3}	10^3

        - The conversion of getting the energy density is done by using the formula:
          - Energy density = Specific energy × $\frac{\text{mass}}{\text{volume}}$
    - Worked example
      - 1200 MW of useful energy = $\frac{1200}{0.25}$ = 4800 MW of input power

        $\frac{4800}{52} = m$

        $m = 92\text{kg}\,s^{-1}$
      - 70% useful, energy = 35GJm^{-3}
        - $q = mc\Delta T$ $= (1)(4.2)(90)$

          $q = 378\text{kJ} = 0.378\text{MJ}$ ← this is how much energy is released with efficiency.

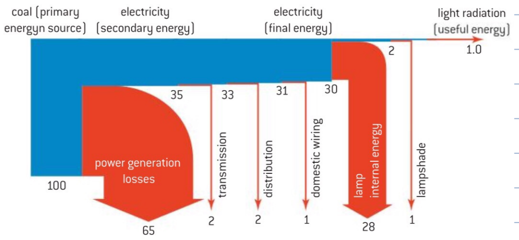
          $\frac{378}{0.7} = 540$ kJ output

          $V = \frac{0.54\text{MJ}}{35000\text{MJ m}^{-3}}$

          $V = 1.54 \cdot 10^{-5}\text{m}^3$ Check if book is wrong. (p.312)
        - 2 liters
    - Thermal power station
      - Where a primary source of energy is converted first into internal energy and then to electrical energy.
        - This can include nuclear fuel, fossil fuel, biomass, or other fuel that can produce internal energy.

- Once the primary energy has been converted to internal energy, all thermal power stations use a common approach to the conversion of internal into electrical energy: the energy is used to heat water producing steam at high temperatures & high pressures.
- Energy from the primary fuel heats water in a pressure vessel to create steam. The steam is super heated (temp >>100°C using high pressure (·100 more than atmospheric pressure)).
  - Water in vessel will directly go to steam which is directed towards a turbine (which is connected to an alternating current electricity generator). The turbines will spin generating electricity
- In the generator the electrical energy is produced when coils of wire, turned by the turbine, rotate in a magnetic field.
- There are three energy transfers going on:
  - Primary energy to internal energy of water.
  - Internal energy to kinetic energy of the turbines.
  - Kinetic energy to electrical energy in the generator.

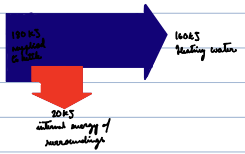
- <u>Sankey diagrams</u>
  - Visual representation of the flow of the energy in a device or in a process.
  - <u>Rules:</u>
    - Each energy source and loss in the process is representing by an arrow.
    - Arrows proportional to the energy it represents.
    - Energy flow is drawn from left to right
    - Energy lost: moves to bottom or top of the diagram.
    - Power transfer as well as energy flows can be represented
  -



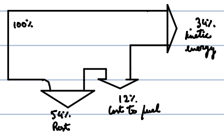
▲ Figure 3 Sankey diagram for a lamp.

- Red arrows represent that is transferred from the system in the form of energy as a result of ΔT.
  - This is lost energy.
  - This is degraded energy.
- 65% is lost to the surroundings, 6% of energy is losts to distribution of the electricity, and to losses in the house wiring. 28% of original is transferred to internal energy (total energy) of the surroundings.
  - Only 1% of energy is useful.

- <u>Worked example</u>
  - 2kW for 90s, over 90s 180kJ produced
  -

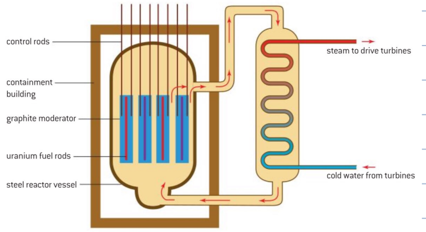


  - 34% converted to kinetic energy, 12% energy lost from fuel
  -



- <u>Primary sources used in power stations</u>
  - <u>Fossile Fules</u>
    - Coal is often crushed into fine powder before being burnt in furnace.

- Negatives to fossile fuels
    - Very long time to accumulate, and long time to replace
    - CO_2 production
    - Significant use in chemical industry
    - Large scale transportation of raw materials needed.
- Nuclear fuel
    - Uranium-235 used in pressurised water reactor.



▲ Figure 6 Basic features of a pressurised water reactor (PWR).

- The fuel needs to contain 3% U-235 before it can be used in a reactor (U-235 is required for fission).
    - U-238 is a good absorber of neutrons and too much U-238 in fuel will prevent fission reaction becoming self sustained.
- The fuel with its boosted proportions of U-235 is said to be enriched.
- Enriched material formed into fuel rods (rods of uranium that are inserted in core of reactor).
    - Most of energy ($\approx$ 200 MeV or $3 \cdot 10^{-11}$ J per fission) is released in form of E_k of the fission fragments and neutrons emitted during the fission.
- Immediately after fission, neutrons are moving at 10^4 km s^{-1}.
    - For self sustained fission neutrons must have $E_k = 0.025$ eV with $v = 2$ km s^{-1}. These are known as thermal neutrons.
- Moderators are H_2 & C-graphite.
    - When neutron collides with moderator, it loses energy to when eventually it becomes a thermal neutron.
- U-238 is a good absorber of high speed neutrons, so moderators are placed near rods slowing down neutron away from rods.
- Fuel rods kept separate from moderators, neutrons move randomly from one to another.
    - Reactor vessel used to facilitate this.
- Good moderator: good absorber of neutrons & inert to extreme conditions of reactor.
- Hydrogen atom is the best moderator (single proton in nucleus) because max energy transferred when neutron hits proton.
  Why?
    - Hydrogen atoms not used because its a good absorber of neutrons.
- To regulate power, control rods are used.
    - Made of Boron (absorbs neutrons very well).
    - Once lowered into reactor the neutrons will be absorbed in the rods meaning fewer neutrons for reaction, meaning less power output.
- Heat exchangers are used to recover heat between two process streams.
    - They carry heat from hot-regions to water.
- Worked example (p. 320)
- Safety issues in nuclear plant
    - Thick steel walls on reactor vessel to withstand high temp and pressures.
        - Also absorb α, β, and some γ & stray neutrons.
    - Vessel enclosed in thick concrete to absorb γ and neutrons.
    - Robots to remove radioactive rods.
- Wind generators
    - Wind moves blades which are mounted on an axle which is connected to an electrical generator.
    - Max power can be estimated with blade area (A).
        - Mass moving through turbine every second is $\rho v A$, ρ = density of air. E_k of air per second is:
            - $P = \frac{1}{2}mv^2 = \frac{1}{2}\rho v A v^2 = \frac{1}{2}\rho A v^3$
    - If a wind turbine has a blade radius "r" then the area A swept out by the blades is πr^2 and the max theoretical kinetic energy arriving at the turbine every second (& max theoretical power) is: $\frac{1}{2}\rho \pi r^2 v^3$.
        - This is the max theoretical value of the available power as there are a number of assumptions

- Most notably one the assumptions is that all the kinetic energy from the wind is being used. This can't be true as the wind won't stop when it hits a wind turbine, it'll continue moving showing that it still has kinetic energy.
- Another factor that makes this value theoretical is that if the wind turbine is part of a wind farm, the other turbines will affect its flow meaning that the flow of wind will be altered leading to a reduction in the energy from turbines at the back of the wind farm.

- In the equations: $\frac{1}{2}\rho\pi r^2 v^3$ and $\frac{1}{2}\rho A v^3$, the equations suggest that increasing the area of the blades or increasing the radius will lead to a bigger E_k for the wind turbine, while this is the case for strong winds, increasing the radius or area will lead to the blades not moving when there are weak winds since the mass is too large.
- Placing a wind mill at the top of the hill will lead to an increase in power output ($\frac{1}{2}\rho\pi r^2 v^3$ or $\frac{1}{2}\rho A v^3$) as the airflow is in a more constraint volume leading to an increase in wind speed.
- Wind turbines also have consequences such as animal habitat impacts, visible and noise pollution, as well as variable output on different days.
- Worked Example
  - Power = P a) $P_n = 8P_{old}$ b) $0.25P_{old} = P_{new}$
  - $r = 25m$, $\bar{v} = 11ms^{-1}$, $\rho = 1.3kg\,m^{-3}$
    - $\frac{1}{2}\rho\pi r^2 v^3 = P$

$$P = \frac{(1.3kg\,m^{-3})\pi(25)^2(11)^3}{2}$$

$$P = 1698718.053\ kg\,m^{-1}s^{-1} \rightarrow P = 1698718.053W$$

$$\underline{P = 1.7MW}$$

    - Because there will be other factors that will make this value almost impossible to achieve, most notably the fact that not all E_k will be transferred from the wind to the wind turbine. As well as if its in a wind farm or not.

- Pumped storage
  - Water can be used as a primary energy source with:
    - Pumped storage plants
    - Hydroelectric plants
    - Tidal barrage
    - Tidal flow systems
    - Wave energy
  - All these sources use of two methods:
    - The gravitational potential energy of water held at a level above a reservoir is converted to electrical energy as the water is allowed to fall to the lower level.
    - The kinetic energy of moving water is transferred to electrical energy as the water flows or as waves move.
      - E.g Hydroelectric plants.
  - Wind farms and nuclear power stations are baseload stations.
    - Work 24/7 converting energy all the time.
  - Pumped storage is when consumer demand for electricity exceeds the production of baseload stations.
  - Pumped storage system involves the use of two water reservoirs, e.g a lake.
    - The reservoirs are connected by pipes.
    - When consumer electrical demand is high, water is allowed to flow through the pipes from the upper reservoir to the lower one via Turbines. Turbines. where are the turbines located?
      - When demand is low the water is pumped back to the top reservoir (using electricity as its cheaper than when they sell it).
  - For a pumped storage system that operates through Δh, the $GPE = mg\Delta h$ where m = mass of water flowing through generator, and g is gravitational field strength.
  - Max power delivered = $P = \frac{m}{t}g\Delta h = (\frac{V}{t}\rho)g\Delta h$.
    - This is the maximum power P available from the water which is equal to the rate at which energy is converted in the machine.
    - t = Time for mass m to move through generator, V is the volume of water moving through water in time t, and ρ is the density of water.
  - Worked example
    - $\Delta h = 260m$, $\left(\frac{m}{t}\right) = 600kg\,s^{-1}$, $\rho = 1000kg\,m^{-3}$, efficiency = 65%.
      - $\Delta GPE = \frac{m}{t}g\Delta h$

$$\Delta GPE = (600)(9.81)(260) \quad (kg\,s^{-1})(m\,s^{-1})(m)$$

$$= 1530360J \quad kg\,m^2s^{-2}$$

$$\Delta GPE = \underline{1.5MJ}$$

$$P = 1530360 \cdot 0.65$$

$$P = 994734MW$$

$$\underline{P = 0.995MW}$$

      - $mgh = (\rho A h)g \cdot \frac{h}{2}$ < Ask how to do this

$$= \frac{1}{2}\rho A h^2$$

- Solar energy
  - Solar heating panels
    - Solar heating panels is a technique for heating water using the sun's energy.
    - A solar heating panel contains a pipes, embedded in a black plate, through which a glycol-water mixture is circulated by a pump.
      - Glycol is a low freezing point substance.
    - The liquid heats up as infrared radiation falls on the panel.
    - The pump circulates the liquid to the hot-water storage cylinder in the building. A heat exchanger system transfers the energy to the water in the storage cylinder.

      Does the energy from the glycol water mixture get removed to then get transferred to the water in the cylinder?
      - A pump is needed because the glycol-water mixture becomes less dense as it heats up and would therefore move to the top of the panel and not heat the water in the cylinder.
  - Solar photovoltaic panels (Solar panels)
    - The photovoltaic materials in the panel convert electromagnetic radiation from the sun into electrical energy.
    - Photovoltaic cells consist of a single crystal of semiconductor which has been doped so that one face is p-type semiconductor and the opposite face is n-type.
      - N-type & P-type indicate the most significant charge carriers in the substance.
        - N-types is electrons.
        - P-types is protons.
      - Normally there's a balance between the charge carriers in both halves of the cell.
    - When energy in form of photons falls on the photovoltaic cell, then the equilibrium is disturbed, electrons are released and gain energy to move from the n-region to the p-region and hence around the external circuit.
      - Electrons exchange energy to the external circuit.
    - One single cell has a small emf of 1V and so banks of are manufactured in order to produce usable currents on both a domestic and commercial scale.
      - Large amount of cells in series will mean large emf, but also a large internal resistance, therefore a mix of parallel and series is used.
    - Power arriving at surface of the panel is IA. Panels have efficiency η which is the fraction of the energy arriving that's converted to internal energy.
      - Total power is: $P = \eta I A$.
  - Worked example
    - $4000 = (650)(0.22)(A)$

      $A = \frac{4000}{650 \cdot 0.22}$

      $A = 27.972027$

      $\approx \underline{28\,m^2}$
    - Solar heating panels: Radiant --> internal
    - Solar panel: Photons --> electrical

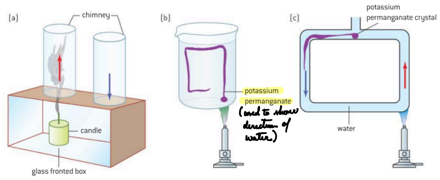
- 8.2 Thermal energy transfer
  - Equations
    - Stefan-Boltzmann equation: $P = e\sigma A T^4$
    - Wien's law: $\lambda_{max}\,(\text{metres}) = \frac{2.90 \cdot 10^{-3}}{T\,(\text{kelvin})}$
    - Intensity equation: $I = \frac{\text{Power}}{A}$
    - Albedo $= \frac{\text{total scattered power}}{\text{total incident power}}$

  - Thermal energy transfer
    - An object with any temperature above absolute zero (0 kelvin) will have internal energy in its molecules.
    - The absolute temperature is equivalent to the average of the kinetic energy of all the molecules in the substance.
    - Given the opportunity, temperature will go from a high temperature to a low temperature.
      - Heat flows from hot to cold.
    - There are three principle to energy flow, conduction, convection, and thermal radiation.
    - Thermal conduction
      - Thermal conduction is the transfer of heat in internal energy by microscopic oscillations of particles.
      - Metals are good thermal conductors and electrical conductors.
        - Poor $^{\text{heat}}$ conductors = glass, some plastics, etc.
      - In conduction process, energy flows through the bulk of the material without any large-scale relative movement of the atoms that make up the solid.
      - Conduction (electrical or thermal) is known as a transport phenomenon.
        - Two mechanisms contribute to thermal conduction:
          - Atomic vibrations occurs in all solids.

- The ions in the solid vibrate in their average fixed position in the solid.
  - The higher the temperature, the greater the average energy, resulting in a higher speed.
- If a metal were heated at one end and cooled at the other, then at the hot end the atoms would start vibrating with greater amplitude and greater mean speed.
  - At the cold end the ions will vibrate with lower amplitude, and lower speed.
  - At the hot end the ions will vibrate increasing the amplitude and energy of other ions will increase as they bump into one another.
    - this leads to energy transferring internally, and the average amplitude and speed increasing in the solid.
    - Internal energy transfer will continue until the bar will have reached thermodynamic equilibrium.
      - thermodynamic equilibrium is when the energy supplied to each ion is equal to that transferred by the ion to its neighbors in the bar or the surroundings.
      - Each region of the bar will be at the same temperature.
- Conduction can occur in gases, liquids, and solids.
  - But, since the intermolecular forces are weaker in gases and liquids (weakest in gases (duh...)), conduction is much less important in many gases and liquids than in convection.
- While thermal conduction is universal in solids, there are other conduction processes that vary in importance depending on the type of solid under discussion.
  - Electrical conductors have covalent (metallic) bonding which releases electrons, known as delocalised electrons.
    - The delocalised electrons are in thermal equilibrium with the positive ions that make up the atomic lattice of the solid.
    - The electrons will interact with one another.
      - Electrons from the hot end of the metal will diffuse along the metal by electron interactions.
    - When an electron interacts with an atom, then energy is transferred back to the atomic lattice.
    - this conduction method depends on the amount of delocalised electrons in the metal.
      - Good electrical conductors which have a lot of delocalised electrons per unit volume will usually be good thermal conductors.

- Convection

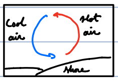
- convection is the free movement of groups of atoms or molecules within fluids (liquids and gases) that arises through variations in density.
  - Conduction involves the microscopic transfer of energy, while convection is a bulk property.
  - It can't take place in solids.
  -



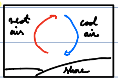
▲ Figure 3 Convection currents.

- The experiments above all involve convection.
  - In all three cases the energy is supplied into a fluid.
- For experiment "a", the candle will heat the air under the tube that will lead out of the box.
  - The air molecules immediately above the flame move further apart decreasing the air density in the region.
  - With a lower density the molecules experience an upthrust and move up through the chimney.
  - The air molecules moving up will mean that there will be a decrease in pressure and cool air will be pulled in from the second chimney.
  - This cycle will continue as the air above the candle will be heated and move up through the first chimney and cool air will come down from the second chimney.
    - this is known as a convection current.
- Convection currents can also occur in liquids, as seen in figure 6.
  - When the base of the beaker is heated, the water at the base will be heated, this will mean that the water will expand and become less dense.
    - The decrease in the density of the water due to the expansion of the water will mean that the water will rise up.
    - this will therefore lead to a convection current where hot water will move up the beaker and colder water will move down the beaker to be heated by the bunsen burner.
  - In figure "3c" the convection current can be seen better.
    - this system uses the same principle where water is heated, expands, moves up, and cool water takes its place.
- A real life example of this is when water is heated on a pan and the water reaches a uniform temperature.

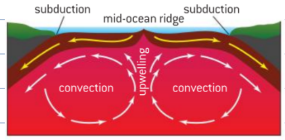
- Examples of convection
    - other examples are:
        - Sea breezes:
            - near the coast during the day the breeze will blow on-shore from the ocean, while at night the breeze will blow on-shore.
                - Day:



                - Night:



            - During the day the land is warmer than the sea, meaning that the heat from ground will go up to the air, while cold air will move in to take the place of the hot air.
                - During the night the process is reversed as the shore is colder than the sea.
        - Convection in the Earth
            - The Earth's core is at a high temperature and this drives convection effects in the part of the planet known as the upper mantle.
                - Two convection currents operate and drive material in the same direction.
                - materials are upwelling (moving from the upper mantle to the surface) creating new land.
                - While in other parts of the world are going back into the Earth (subduction).
                -

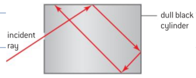


▲ Figure 5 Convection currents in the Earth's mantle.

        - Winds blowing
            - Essentially the winds blow due to uneven heating of Earth's surface by the sun.
                - where the land or sea heat up, the air just above them rises and creates an area of low pressure.
                    - this low pressure will mean that cold air will move in to take the place of the hot air.
                - where the air will be falling a high pressure zone is set up.
                    - the air moves from high to low pressure areas causing wind.
- Worked example
    - Explain the role of convection in the flight of a hot-air balloon.
        - My answer: the way that a hot-air baloon works is by having a flame which will heat its immediate surroundings. this will expand the air causing it to move up as its less dense, bringing the hot air baloon up. As the hot air reaches the extremities of the baloon it will cool down resulting in the cold air moving down (as its more dense than the hot air) and will then reach the flame again which will re-heat the cold air creating a convection current.
        - Book's answer: the air in the gas canopy is heated from below and the temp increases.
            - the hot air in the baloon expands and its density will decrease below that of the cold air outside of the baloon.
            - this will create an upward force on the baloon.
    - Explain why having marshmallows in hot chocolate will mean that the loss of energy will be slowed down:
        - the marshmallows will trap the hot air from the hot chocolate.
            - this will mean that the marshmallows will absorb the energy, and since its a bad conductor of thermal energy the top of the marshmallow will be cold.
            - this will reduce the amount of convection occuring at the surface.
- Thermal radiation
    - Basics
        - Thermal radiation is the transfer of energy by means of electromagnetic radiation.
            - Electromagnetic radiation is unique as a wave because it doesn't require a medium to propagate (move).
                - On the other hand, conduction and convection require a bulk material to transfer energy.
            - An obvious example of thermal radiation is the energy being received from the sun which travels 150 million km of space.
        - Thermal radiation has its origins in the thermal motions of particles of matter.
            - Atoms contain charged particles and when these charges are accelerated they emit photons. Which are what make up the radiation.

- Black surfaces are very good at radiating and absorbing energy.
    - Shiny or white surfaces reflect energy rather than absorbing it, and are bad at radiating energy.

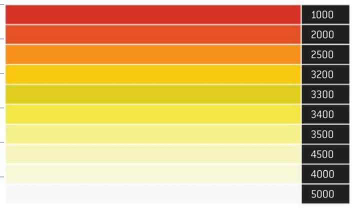
- Black body radiation
    - Black surfaces are good radiators and absorbers, but poor reflectors of thermal energy.
    - A black body is one that absorbs all the wavelengths of electromagnetic radiation that fall on it.
        - this is an ideal system.
        - A practical apparatus would be to have a hole in the wall where there is a completely black



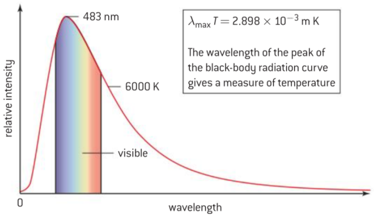
▲ Figure 7 A black-body enclosure.

- When enclosures, such as furnaces, are heated to high temperatures, radiation emerges from the
    - the radiation appears to be colored depending on the temperature of the enclosure.
    - At low temperatures the radiation is in the infra red spectrum.
        - As the temperature increases the color emitted will change first to red, yellow, eventually becoming white when the temperature is high enough.
        - the intensity of the radiation coming from the hole is higher when the temperature is higher.
        - the emission from the hole isn't dependent on the material from what the hole is made of.

colour and temperature/K



- The emission spectrum from a black body
    - Although the predominant color that emerges from the black body is of one color, there are other wavelengths which are emitted.
        - A spectrometer will be used to show the wavelengths emitted.
            - A spectrometer will measure the intensity of the radiation at a particular wavelengths.
            - $I = \frac{P}{A}$, P = Power, A = area, I = Intensity.
            - Units: $W m^{-2}$ or $J s^{-1} m^{-2}$.

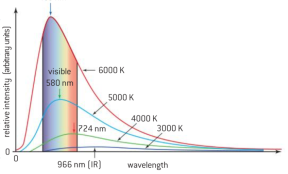


$\lambda_{max} T = 2.898 \times 10^{-3}$ m K

The wavelength of the peak of the black-body radiation curve gives a measure of temperature

▲ Figure 9 Intensity against wavelength for a black body at the temperature of the Sun. (surface temp)

- the important features are:
    - There is a peak value at ≈ 500nm.
        - somewhere between green & blue light.
    - there are significant radiations at all visible wavelengths.
    - there is a steep rise from zero intensity.
        - line doesn't go through the origin.
    - At large wavelengths, beyond the peak of the curve, the intensity falls to low levels and approaches zero asymptotically.



▲ Figure 10 Intensity against wavelength for black bodies at four temperatures.

- As the temperature increases:
    - The overall intensity at each wavelength increases.
    - The total power emitted per square meter increases.
        - Total area under graph increases.
    - The curve shines towards shorter wavelengths (higher frequencies).
    - The peak of the curve moves to shorter wavelengths.
- Wien's displacement law
    - The height of the curve and the overall width depends on the temperature alone.
    - Wien's displacement law states that the wavelength at which the intensity is a maximum "λ_{max}" in meters is related to the absolute temperature of the black body T by:
        - $\lambda_{max} = \frac{b}{T}$
            - b is the Wein displacement constant, $2.9 \cdot 10^{-3}$ m K.
- Stefan - Boltzmann law
    - The Stefan - Boltzmann law states that the total power "P" radiated by a black body is given by:
        - $P = \sigma A T^4$
            - σ is the Stefan - Boltzmann constant with the value $5.7 \cdot 10^{-8}$ W m^{-2} K^{-4}.
            - A is the surface area of the object.
            - T is the absolute temperature.
    - The law is about the power radiated by the object, which is the same as the energy radiated per second.
- Grey bodies and emissivity
    - Grey bodies are what objects that aren't black bodies are called.
        - A grey object at a particular temperature will emit less energy per second than a perfect black body of the same dimensions, at the same temp.
    - The quantity known as emissivity, "e", is the measure of the ratio between the two powers:
        - $e = \frac{\text{power emitted by a radiating body}}{\text{power emitted by an identical black body}}$
    - For a real material, the power emitted can be written as: $P = e \sigma A T^4$
        - A black body will have an emissivity value of 1.
        - An object which completely reflects radiation without absorption at all will have an emissivity of 0.
- Worked example
    - $T = 5800$ K, $r = 7.0 \cdot 10^8$ m $4 \cdot 10^{26} \cdot 3600 = \underline{1.4 \cdot 10^{30}}$ J

$$P = \sigma A T^4$$
$$= (5.7 \cdot 10^{-8})(4\pi(7 \cdot 10^8)^2)(5800)^4$$
$$= 3.97 \cdot 10^{26}$$
$$= 4 \cdot 10^{26} \text{ W} \checkmark$$

- $P = \sigma A T^4$

$$T = \sqrt[4]{\frac{48}{(5.7 \cdot 10^{-8} \cdot 2\pi \cdot 1.2 \cdot 10^{-3} \cdot 0.05)}}$$
$$= 1232$$
$$\approx \underline{1200 \text{ K}}$$

- Power emitted $= \sigma A T_1^4$

The power absorbed by the surroundings are $\sigma A T_2^4$

Net power loss $= \sigma A (T_1^4 - T_2^4)$

- Sun and solar constant
    - A black body at the temperature of the sun has just under half of its radiation in our visible region.
        - Roughly the same amount in infra-red, and 10% in the UV spectrum.
    - It's the difference between the incoming radiation and the emitted radiation that is emitted by the Earth that determines the energy gained by the Earth by the sun.
        - The amount of energy that arrives at the top of the atmosphere is known as the "solar constant".
            - Precise definition: The solar constant is the amount of solar radiation across all wavelengths that is incident in one second on one square meter at the average distance of the Earth from the sun on a plane perpendicular to the line joining the center of the sun and the center of the Earth.
    - The energy from the sun emits $4 \cdot 10^{26}$ J in one second.
        - The solar constant is given by $\frac{4 \cdot 10^{26}}{2.8 \cdot 10^{23}} = 1400$ W m^{-2}, which is $5 \cdot 10^{-10}$% of the sun's total output.
            - The intensity $= \frac{P}{A} = \frac{4 \cdot 10^{26}}{(4\pi \cdot (1.5 \cdot 10^{11})^2)} = \underline{1400 \text{ W m}^{-2}}$.
        - The sun's solar constant varies due to:
            - The output of the sun varies by 0.1% during its principle 11-year sunspot cycle.

$$I_{in} = \frac{S \pi R^2}{4 \pi R^2}$$
$$I_{in} = \frac{S}{4}$$

    - the Earth's orbit is elliptical (oval) with the Earth being closer to the sun in Jan compared to July.
        - Equals to about 7% difference during those months for the solar constant.
    - longer period cycles occur in the sun that last for hundreds of years.

- Energy balance in the Earth surface - atmosphere system
    - the solar constant is the power incident on the top of the atmosphere.
        - It's not the power that arrives at ground level.
    - As the radiation from the sun travels through the Earth's atmosphere it will undergo losses that will reduce the energy arriving at the Earth's surface.
        - the degree of absorption depends on the position in the sky.
            - When the sun is lower in the sky (dawn & sunset), its radiation will have to pass through a greater thickness of atmosphere resulting in more scattering and absorption.
    - When energy arrives at the surface of the Earth, it won't necessarily remain there.
        - Since the Earth's surface isn't a black body (perfect emitter of radiation and perfect absorber of radiation), some of the radiation will be reflected.
            - the reflective capabilities of the surface is known as the albedo.
                - the albedo has the symbol "a". $a = \frac{\text{energy reflected by a surface in a given time}}{\text{total energy incident on the surface in a given time}}$
                - Albedo has no units.
                - the albedo varies from 0 for a surface which doesn't reflect any radiation (black body) to 1 for an object which absorbs no radiation.
                    - the average annual albedo for Earth is 0.35 which means 35% of all radiation from the sun is reflected.
                    - the 0.35 is an average as the albedo depends on:
                        - the number of clouds and their thickness will alter the albedo.
                            - the thicker the clouds the greater the albedo.
                        - the terrain will also affect the albedo.
                            - Fresh snow has a very high albedo, meaning that it will reflect radiation from the sun very well.
                            - Mixing snow with a material such as soots or soil will make it melt as they will absorb the radiation, become hotter, and melt the snow.

- The greenhouse effect and temperature balance
    - Even though Earth & Moon are essentially the same distance from the sun, Earth is at 290K, while the moon is at 255K.
        - this is due to the presence of an atmosphere around Earth.
    - this is due to the greenhouse effect where certain gases (CO_2, O_3) in the Earth's atmosphere trap energy within the Earth's system leading to an increase in the average temperature of the Earth.
        - the most important gases are: $\left(\frac{\Lambda}{4}+R\right)=e\sigma T^4$
            - CO_2, $H_2O_{(g)}$, CH_4, and N_2O.
            - O_3 also contributes to the greenhouse effect.
            - the atmosphere is 70% nitrogen, 20% O_2, and 1% of it is N_2O, CO_2, CH_4, H_2O.
                - the molecular structures of greenhouse gases means that they absorb UV and infra red radiation from the sun.
                - Visible light isn't absorbed readily from these gases, therefore its absorbed by surfaces.
                    - leading to temp rises.
    - Due to the surface temperature of the Earth being lower than the sun's the λ_{max} will lie in the infra-red spectrum.
        - As the Earth will emit its radiation, in the infra red spectrum, the gases in the atmosphere will absorb the radiation.
        - the atmosphere will then re-radiate the energy in all directions (including back to Earth).
            - this energy has been trapped in the system.
    - the system is in a state of dynamic equilibrium where the total energy incident on the system from the sun equals the total energy being radiated away from the Earth.
    - there are differences between natural and man-made greenhouse effects:
        - "Natural" greenhouse effects are greenhouse effects that occur due to naturally occurring levels of gases responsible.
        - Man-made greenhouse effects are where humans produce an excess of greenhouse gases, further increasing the temp rise.

- Why greenhouse gases absorb energy
    - UV and long wave infra-red radiations are absorbed by the atmosphere.
        - Photons from the UV region of the electromagnetic spectrum are energetic and have enough energy to break the bonds within the gas molecules.
        - this will lead to free radicals and ionic materials in the atmosphere.
            - E.g O_3 being produced by splitting UV.
    - Infra-red photons don't have the necessary energies to break the molecules apart.

- When the frequency of the photon matches the vibrational state in a greenhouse gas molecule, called **resonance**.
- There are 4 vibrational modes that a carbon dioxide can have.
  - This is due to the CO_2 molecule having a linear arrangement with a double bond on each Oxygen.
  -

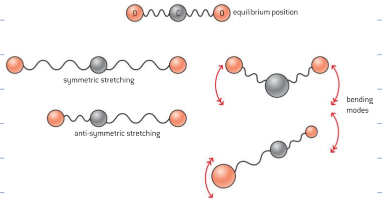


Figure 12 Vibrational states in the carbon dioxide molecule.

  - Each one has a characteristic frequency.
  - If the frequency of the radiation matches the CO_2 molecules, then the molecule will be stimulated into vibrating with the appropriate mode and the energy of the vibration will come from the incident radiation.
    - The vibrational absorption occurs at $\lambda = 2.7\,\mu m$, $4.3\,\mu m$, and $15\,\mu m$.

- **Modelling the climate balance**
  - The full solar constant (1400 J) doesn't reach the surface.
    - About 25% of the incident energy is reflected by the clouds and particles in the atmosphere.
    - 25% is absorbed by the atmosphere.
    - 6% reflected by the Earth's surface.
  - The Sun's incoming radiation will fall on the portion of Earth's surface which is at a normal to the Sun's radiation.
    - I.e a circle of area equal to $\pi \cdot (\text{radius of Earth})^2$.
    - However, the radiation has to be averaged over the whole of the surface which is $4\pi \cdot (\text{radius of Earth})^2$.
      - This will mean that the average power per square meter is $\frac{1380}{4} = 345\,W$. ← Accurate solar constant value.
  - The albedo will have to take into account to give an effective mean power at one square meter of the surface of: $(1-\alpha)\cdot 350$.
    - The average "α" value for Earth is 0.3. Therefore, the mean power absorbed by the surface per square metre is 245 W.
    - This will allow a prediction of the temperature of a black body that emits $245\,Wm^{-2}$.
      - $245 = \sigma T^4$

        $T = \sqrt[4]{\frac{245}{5.67\cdot 10^{-8}}}$

        $= \underline{\underline{256\,k}}$

        Note: When to calculate the temperature of a planet you will have to use $P = \sigma A T^4$.

        $T = \sqrt[4]{\frac{I_{in}}{\sigma}}$
      - The value "256" is approximately that of the Moon's surface temperature.
      - This is due to the fact that it was assumed that the Earth emits $245\,Wm^{-2}$, and that this energy leaves the atmosphere completely.
        - This is only true for an atmosphere that is completely transparent to all wavelengths.
        - This isn't the case as the atmosphere will absorb energy in the infra-red and UV spectrums.
    - Therefore, a more accurate representation would be that 100% of the visible light will pass through, and 0% of all infra-red and UV light passes through.
      - The UV and infra-red radiation won't be transmitted as it will be absorbed and re-radiated in all directions with some returning to Earth.
      - For the correct temperature to be calculated, the area of the graph must be reduced so that the area is equal to $245\,Wm^{-2}$.
        - For the emission of the surface to equal the incoming energy from the Sun, accounting absorption, the surface temp must be equal to 290 K.
  - The actual transmittance pattern is shown below:
    -

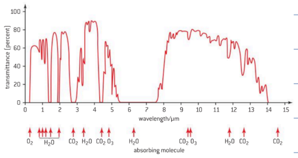
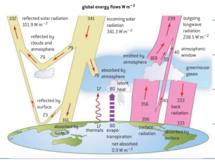
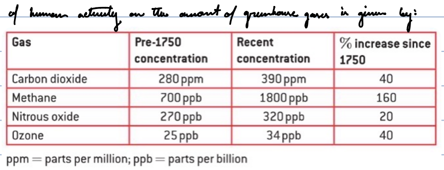


Figure 16 Transmittance of the atmosphere in the infra-red.

- **The energy balance of the Earth**
  - The surface-atmosphere energy balance system is shown below:
    -



- Global warming
    - Many models have been suggested to explain global warming, they include:
        - Changes in the composition of the atmosphere, leading to an enhanced greenhouse effect.
        - Increase solar flare activity.
        - Cyclic changes in the Earth's orbit.
        - Volcanic activity.
        - Human burning of fossil fuels
    - The extent of human activity on the amount of greenhouse gases is given by:
        - 

Gas	Pre-1750 concentration	Recent concentration	% increase since 1750
Carbon dioxide	280 ppm	390 ppm	40
Methane	700 ppb	1800 ppb	160
Nitrous oxide	270 ppb	320 ppb	20
Ozone	25 ppb	34 ppb	40

ppm = parts per million; ppb = parts per billion

        - Values before 1750 are determined with the sources:
            - Analysis of Antarctic cores.
                - the composition of the atmosphere of an era can be determined by when the snow originally fell on the continent.
            - Analysis of tree rings.
                - The rings found in trees give information about the temp and lengths of a season, and the rainfall.
            - Analysis of water levels in sedimentary records from lake beds.
                - these are used to identify historical changes in water levels.
        - The enhanced greenhouse effect results from changes to the concentration of the greenhouse gases.
            - As the amounts of these gases increase, more absorption occurs for when energy enters and when the surface reflects it.
                - the absorption peaks will also increase when a gases concentration increases.
                - the surface will therefore need to increase its Temp in order to emit sufficient energy at sea level so that the emission by the Earth from the top of the atmosphere will equal the incoming energy from the Sun.