Topic 8

Energy Production

Syllabus

8.1 Energy Sources

- Understand
  1. Specific energy and energy density of fuel sources
  2. Sankey diagrams
  3. Types of Primary and secondary energy sources
  4. Renewal and non-renewal energy sources

8.2 Thermal energy transfer

- Understand
  1. Black body radiation
  2. Conduction, convection and thermal radiation
  3. Albedo and emissivity
  4. Solar constant
  5. The greenhouse effect
  6. Energy balance in the Earth surface-atmosphere system

8.1 Primary and Secondary Energy

- We use many different types of energy sources in our daily lives. There is a distinction between two basic types of energy source we use
  1. Primary Sources
  2. Secondary Sources

Definitions

- Primary Source of energy is one that has not been transformed or converted before use by the consumer. E.g. Fossil fuel burnt directly in a furnace.

- Secondary source is one that results from the transformation of a primary sources. E.g. The electricity we used is generated from the conversion of a primary source of energy.

Primary Source of energy

- Primary sources can be further divided into two groups
  - Renewable sources
  - Non-renewable sources.

Primary Source of energy

- Renewable resources of energy can be replenished in relatively short time whereas non-renewable sources can be replace but only over very long geological times.

- Coal and oil, both non-renewable, are produced when vegetable matter buried deep below ground is converted the effect of high pressure and temperature over hundreds of million of years.

Primary Source of energy

- Some of the primary sources that are used in the world today are shown in the table below.

Energy Sources			
		Source	Energy Form
Non-renewal sources	Nuclear Fuels	Uranium-235	Nuclear
	Fossil fuels	Crude oil	Chemical potential
		Coal	
		Natural gas	
Renewal sources		Sun	solar
		Water	Kinetic
		Wind	Kinetic
		Biomass	Chemical potential
		Geothermal	Internal

Specific Energy and Energy Density

- Specific energy indicate the number of joules of energy that can be released per unit mass of fuel consumed.

$$specific\ energy = \frac{amount\ of\ energy\ liberated}{mass\ of\ fuel\ consumed}$$

- Energy density is the energy liberated per unit volume of fuel consumption. It is measured in Joules per m^3.

$$energy\ density = \frac{amount\ of\ energy\ liberated}{volume\ of\ fuel\ consumed}$$

Specific Energy and Energy Density

- Fuel choice can be particularly influenced by energy density and specific energy of fuel when the fuel needs to be transported because the greater the amount of fuel that needs to be transported, the greater the cost required to move the fuel.

Fuel	Specific Energy/ MJ kg^{-1}	Energy Density/ MJ m^{-3}
Wood	16	1×10^4
Coal	20 –60	$(20 – 60) \times 10^6$
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 fission)	3×10^8	6×10^{15}
Water falling through 100 m in a hydroelectric plant	10^{-3}	10^3

Specific Energy and Energy Density

For coal to supply 500 MW to a power station at 35% efficiency:

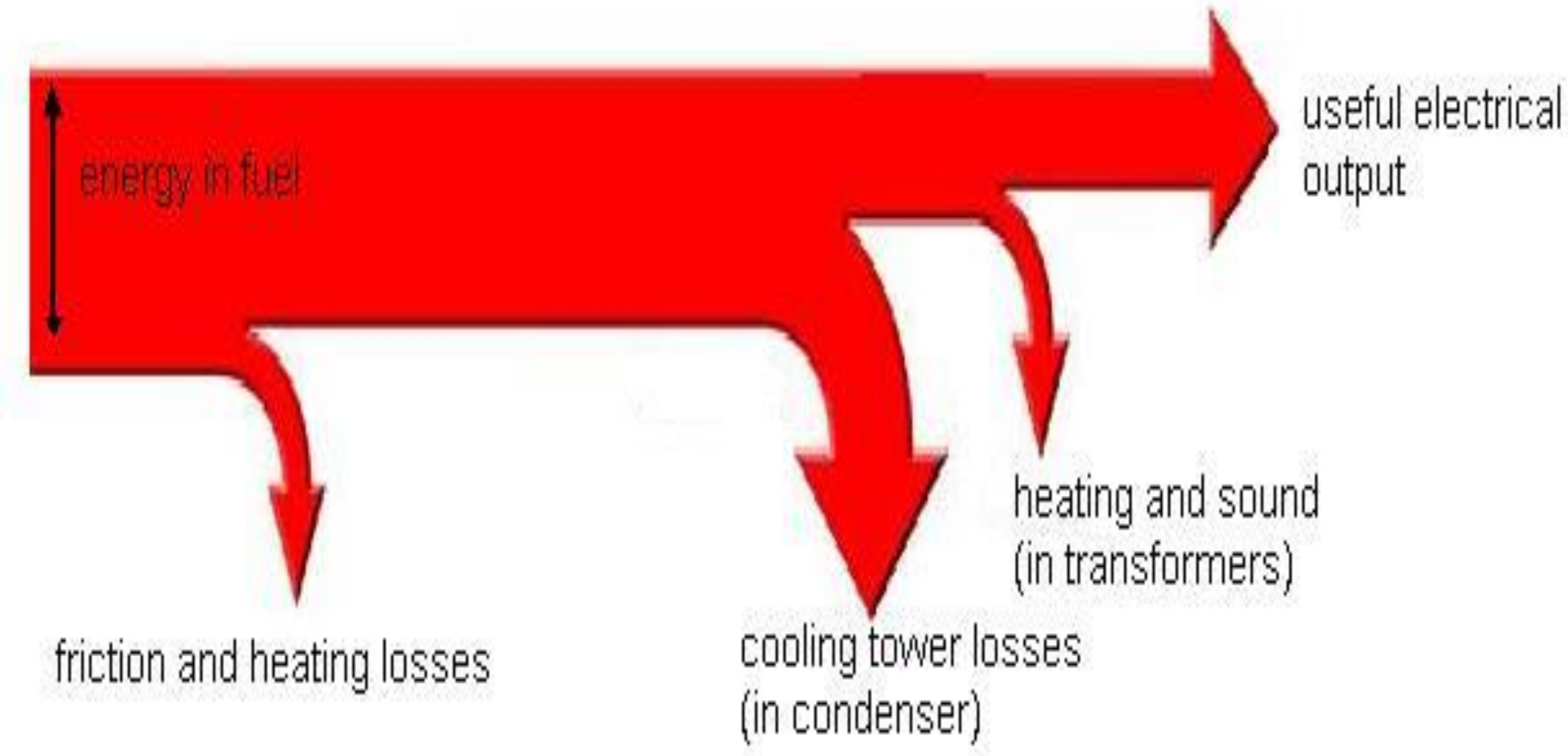
Electrical power supply = 500 MW = 5×10^8 J s^{-1}.
Power released from fuel = 5×10^8 / efficiency
= $5 \times 10^8 / 0.35$
= 1.43×10^9 J s^{-1}

Specific Energy of coal = 33 MJ kg^{-1}

Rate of coal use = $1.43 \times 10^9 / 3.3 \times 10^7$ kg s^{-1}
= 43.3 kg s^{-1}
= 1.56×10^5 kg hr^{-1}
= 160 tonnes hr^{-1}

Sankey Flow Diagram

- The diagram is used to show where the energy in the fuel goes.



Overall Efficiency of fossil-fuel power station

Fossil fuel	Typical efficiency	Maximum efficiency
Coal	35%	42%
Oil	38%	45%
Natural Gas	45%	52%

Note: The efficiency of different power stations depends on the design. These designs are never 100% efficient because large amounts of heat are lost in the process through heat, sound, or cooling tower losses.

Advantages of fossil-fuel power station

- High energy density/specific energy
- Relatively easy to transport
- Cheaper than other sources of energy
- Can be used anywhere with good transport links and water availability
- Can be used directly in the home to provide heating

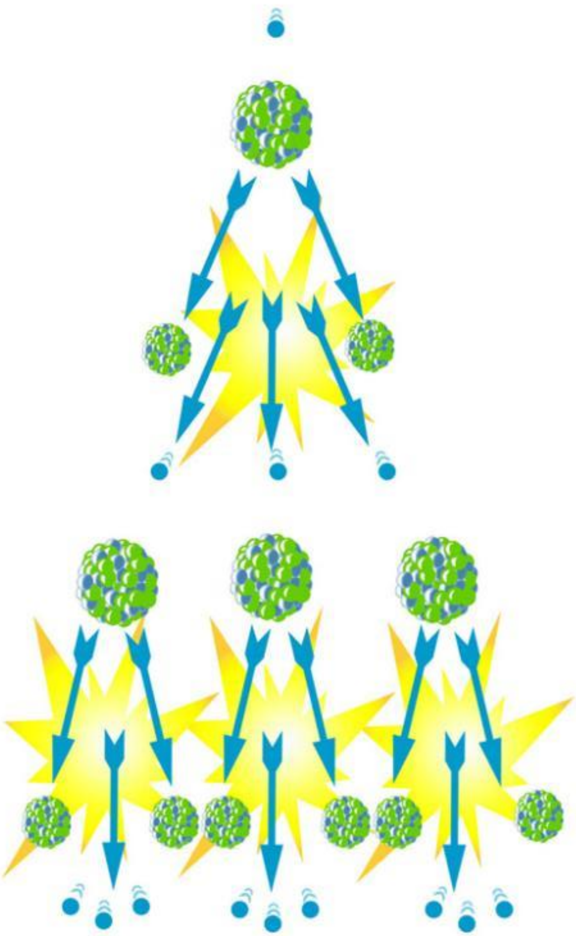
Disadvantages of fossil-fuel power station

- Combustion products include greenhouse gases and can cause pollution (e.g. acid rain)
- Extraction or mining for fossil fuels can damage the environment.
- Non-renewable
- Coal-fired power stations need large amounts of fuel.

Nuclear fuel power station

- Nuclear power is the production of energy through a fission reaction. Producing nuclear power through fusion reactions is also possible in theory, but as it requires temperatures high enough to ionize atomic hydrogen into a plasma state, the principal design challenge is maintaining and confining plasma at sufficiently high temperature and density.

Fission reactions



- A chain reaction is created as an individual reaction requires that a incoming neutron causes a uranium nucleus to split apart. The fragments created by the split include more neutrons, which go on to initiate further reactions.

Fission reactions

- Lower-energy neutrons (around 1 eV) favour fission.

- Critical mass is the minimum mass needed to sustain a chain reaction. It depends on the exact nature of the fuel being used and the shape of the assembly.

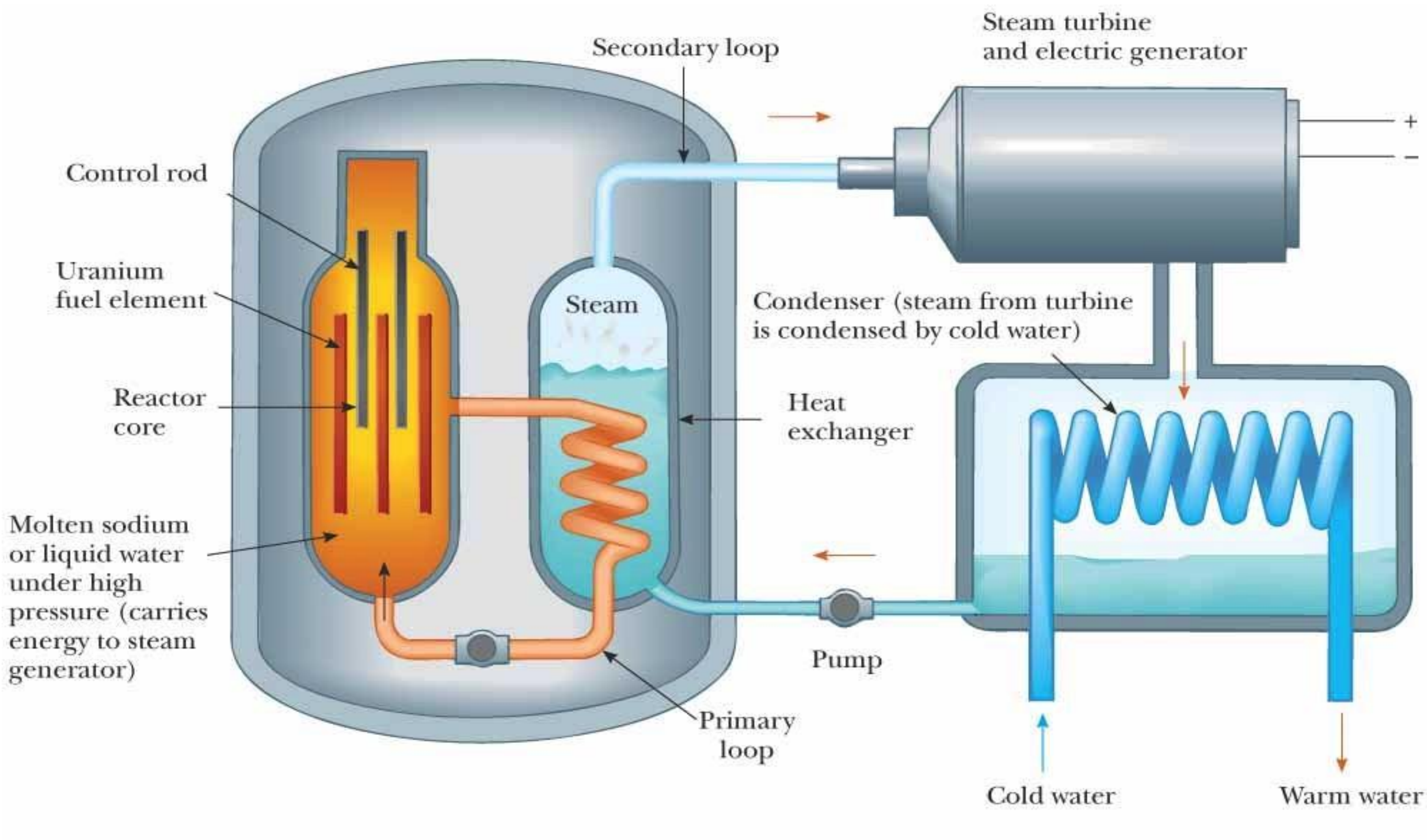
- The chance of a neutron causing fission depends on the number of potential nuclei ‘in the way’ and the speed of the neutrons.

Controlled vs Uncontrolled

- Uncontrolled fission produces a huge amount of energy in a very short amount of time. This makes nuclear weapons highly destructive.

- Controlled nuclear reactions limit the rate at which nuclear fission takes place by limiting the number of neutrons. Energy is thus released at a slow rate so that nuclear energy may be used for power production.

Parts of a Nuclear Reactor (Pressurized Water Reactor)



Parts of a Nuclear Reactor

- Collisions between the neutrons and the nuclei of the **moderator** slow the former down to allow further reactions to take place.
- **Control rods** are movable rods that readily absorb neutrons in the reaction chamber as necessary to control the chain reaction.
- **Heat exchangers** allow the nuclear reactions to occur in a place that is sealed off from the environment. The reactions increases the core temperature so water and steam transfer the thermal energy away to turn the turbines.

Fuel enrichment and Reprocessing

- Naturally occurring uranium contains less than 1% of Uranium-235. Enrichment is the process by which the percentage composition of Uranium-235 in the fuel rods is increased. This will make nuclear fission more probable.

- A by-product of peaceful use of uranium for energy production is Plutonium-239 (which is made by neutron- capture by Uranium-238 in the fuel rod). Depleted fuel rods will contain significant amounts of Plutonium-239. Reprocessing involves treating depleted fuel rods to recover uranium and plutonium.

- Another type of nuclear reactor called fast-breeder reactors use Plutonium as fuel.

- Plutonium-239 could also be used for the production of nuclear weapons.

Plutonium-239

- Pu-239 is capable of sustaining fission reactions hence it is an important nuclear energy source. It is produced by neutron-capture by Uranium-238.

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U \quad \text{(neutron capture)}$$

$$^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}\beta + \tilde{v} \quad \text{(beta decay)}$$

$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}\beta + \tilde{v} \quad \text{(beta decay)}$$

Advantages of Nuclear Power

- Extremely high specific energy because a great deal of energy is released from a very small mass of uranium.

- Reserves of uranium are large, especially compared to oil.

Disadvantages of Nuclear Power

- Process produces radioactive nuclear waste that is currently just stored.

- Larger possible risk if anything should go wrong.

- Non-renewable (but does last a long time)

- Health and safety risks

Health and Safety Risks

- Uncontrolled nuclear fission due to miscalculations with the power plant equipment can lead to a thermal meltdown of the core. The radioactive material can kill and cause genetic mutations when living creatures in the surrounding area are exposed.

- A significant amount of the radioactive nuclear waste will take millions of years to decay, hence disposal is an issue. The current solution is to bury the waste in geologically secure sites.

Health and Safety Risks

- Because of the possible terrible scale of disaster if a nuclear power plant is exploded some critics believe that it could be a target for terrorist attacks.

- Transportation of the uranium from the mine to the power station and of the waste to the reprocessing plants need to be secure and safe.

Health and Safety Risks

- Mining nuclear energy ores is also dangerous so extra precautions are needed to protect miners.

- By-products of civillian use can be used to produce weapons.

Fusion reactor challenges

- Fusion reactors theoretically could produce large amount of energy using hydrogen, which is in plentiful supply, and not produce significant amounts of radioactive waste.

- However, the reaction requires creating temperatures high enough to ionise atomic hydrogen into a plasma state. Currently, scientists are still working on how to maintain plasma and confine it as sufficiently high temperatures and density for fusion to take place.

Wind Power

8.4.18 Outline the basic features of a wind generator

8.4.19 Determine the power that may be delivered by a wind generator, assuming that the wind kinetic energy is completely converted into mechanical kinetic energy, and explain why this is impossible

8.4.20 Solve problems involving wind power

Wind Power

- Wind power is the conversion of the kinetic energy of wind into electric energy
- The original source of the energy is the Sun
  - Different parts of the atmosphere are heated to different temperatures
  - The temperature differences cause pressure differences, due to hot air rising or cold air sinking, and thus air flows as a result

Solar energy —(heating of earth)→ kinetic energy of wind → kinetic energy of turbines → electrical energy

Mathematics

Area ‘swept out’ by the blades of the turbine = A = πr^2

In one second, the volume of air that passes the turbine = vA

So, kinetic energy of the air that passes the turbine in one second

$$= \frac{1}{2} m v^2$$

$$= \frac{1}{2} (vA\rho) v^2$$

$$= \frac{1}{2} A \rho v^3$$

Wind Power

- In practise, the kinetic energy of incoming wind is easy to calculate, but it cannot all be harnessed
  - The wind turbine cannot be one hundred per cent efficient
- A doubling of the wind speed would mean that the available power would increase by a factor of eight

Advantages of Wind Power

- Very ‘clean’ production
  - No harmful chemical by-products
- Renewable source of energy
- Source of energy is free

Disadvantages of Wind Power

- Source of energy is unreliable
  - Could be a day without wind
- Low energy density
  - A very large area would need to be covered for a significant amount of energy
- Some consider large wind generators to spoil the countryside
- Can be noisy
- Best positions for wind generators are often far from centres of population

Pumped Storage

- Wind farms and nuclear power station are known as baseload stations. They operate 24 hours a day, 7 days a week converting energy all the time. However there are occasions when demand for energy exceed the output of these baseload stations. Pumped storage is one way to make up for this deficit.

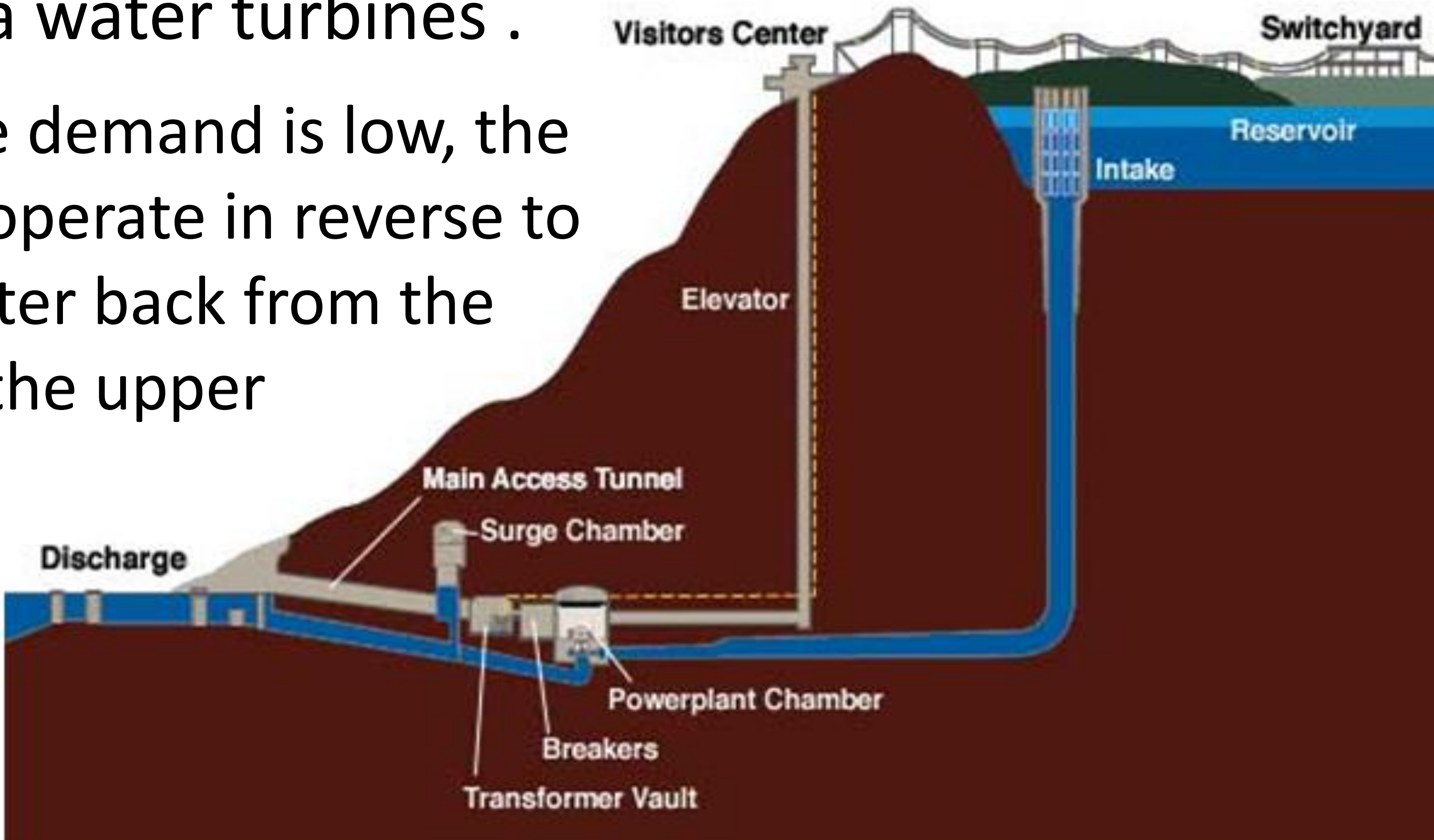
Pumped Storage system

- Pumped storage system convert gravitational potential energy of water into electrical energy as water is allowed to fall to the lower level.

gravitational potential energy of water → kinetic energy of water → kinetic energy of water turbines → electrical energy

Pumped Storage system

- The system involves the use of two water reservoirs. These reservoirs are connected by pipes.
- When demand is high, water is allowed to run through the pipers form the upper reservoir to the lower via water turbines .
- When the demand is low, the turbines operate in reverse to pump water back from the lower to the upper reservoir.



Pumped Storage system

- So the maximum power available from the water is equal to the rate at which gravitational potential energy is converted in the turbine.

$$P = \frac{mg\Delta h}{t}$$

$$= \frac{(\rho Vol)g\Delta h}{t}$$

Solar Power

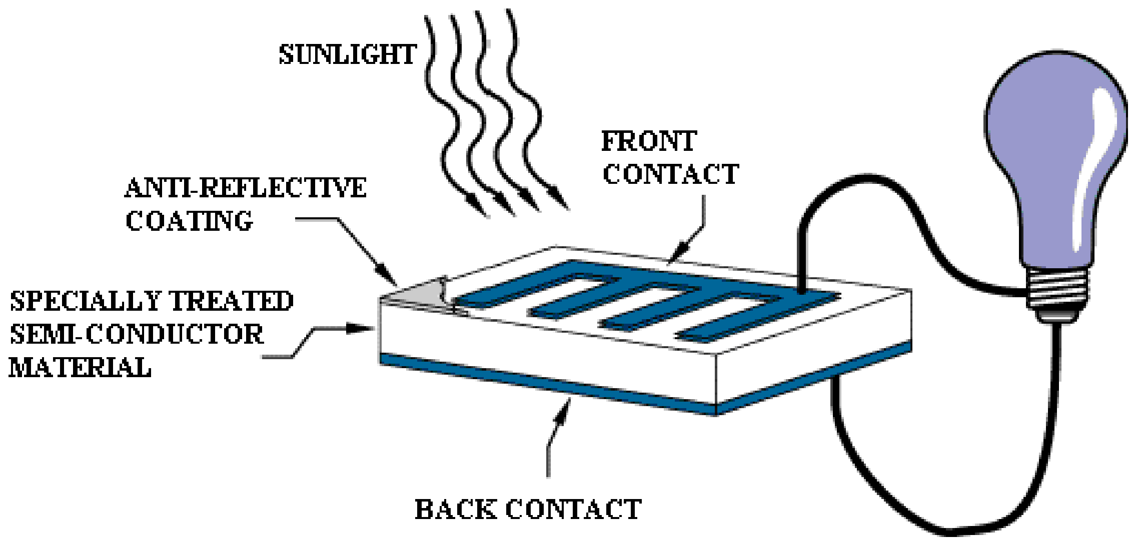
8.4.12 Distinguish between a photovoltaic cell and a solar heating panel

8.4.13 Outline reasons for seasonal and regional variations in the solar power incident per unit area of the Earth's surface

8.4.14 Solve problems involving specific applications of photovoltaic cells and solar heating panels

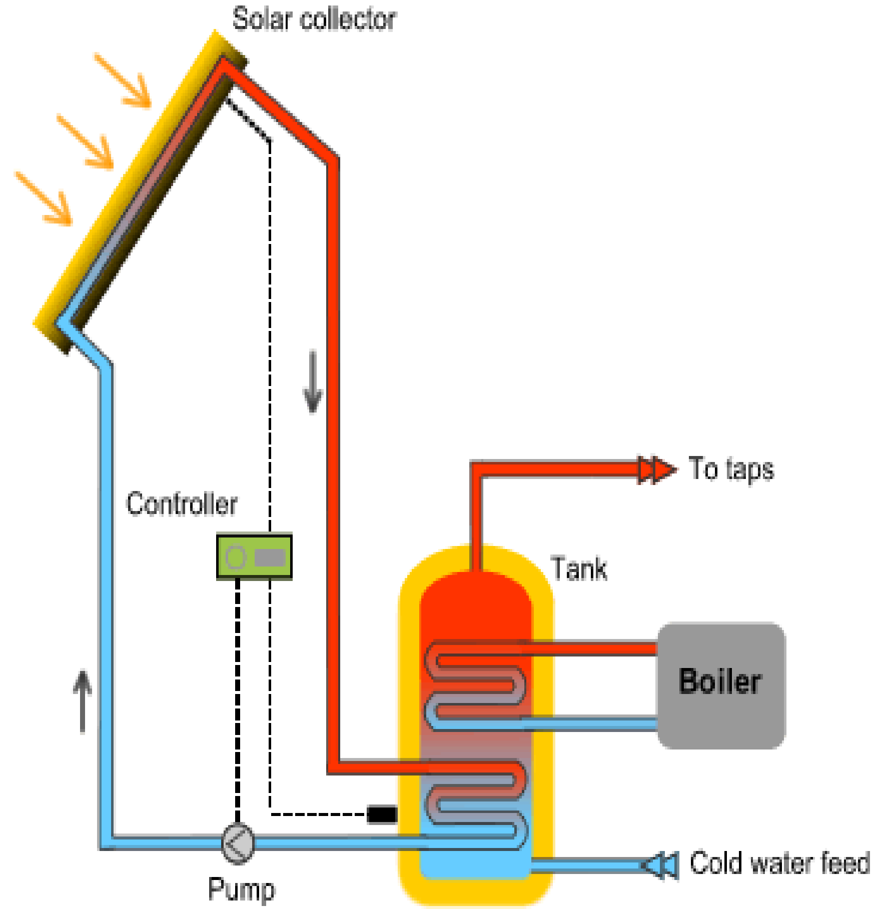
Solar Power

- Solar Power is the conversion of sunlight into different forms of energy, and can be harnessed in two ways; using photovoltaic cells or a solar heating panel



Solar Heating panels

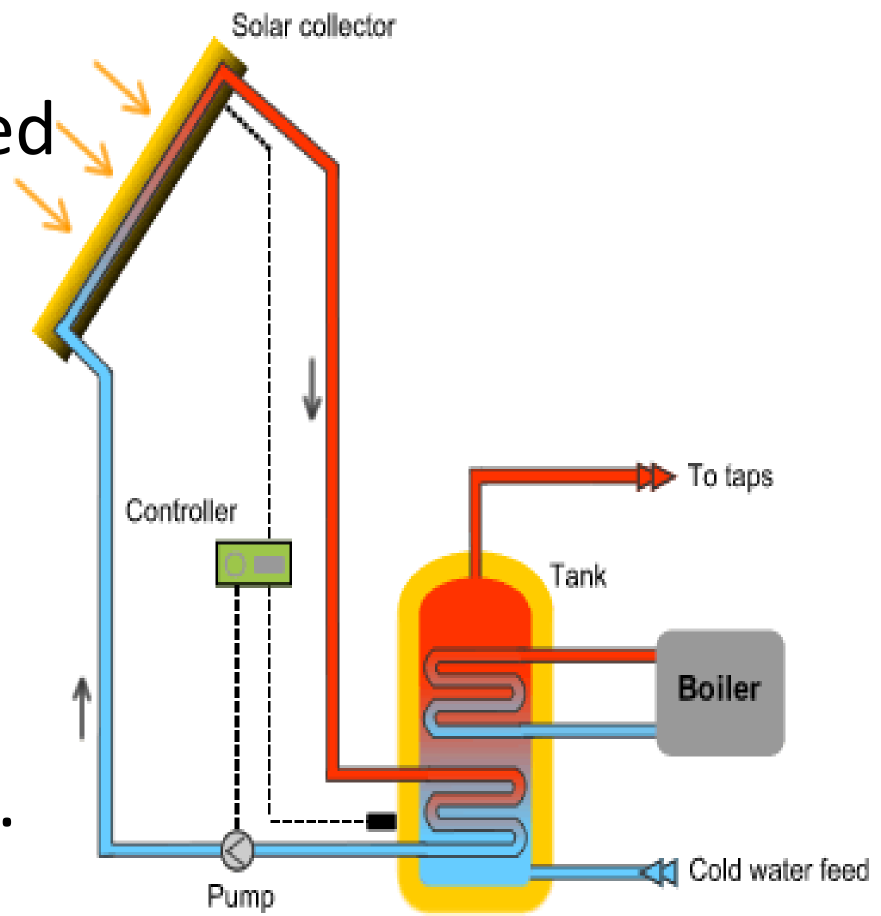
- Designed to capture as much thermal energy as possible
- The hot water that is typically produced can be used domestically and would save on the use of electrical energy.



- Solar Energy —Solar heating panels→ Internal energy of the fluid

Solar Heating panels

- A solar heating panel contains a pipe, embedded in a black plate, through which a glycol-water mixture (low freezing point) is circulated b a pump).
- The liquid heats up as infra-red radiation falls on the panel.
- The pump circulate the liquid to the hot water storage cylinder in the building.
- A heat exchanger systems transfer the energy to the water in the storage cylinder .

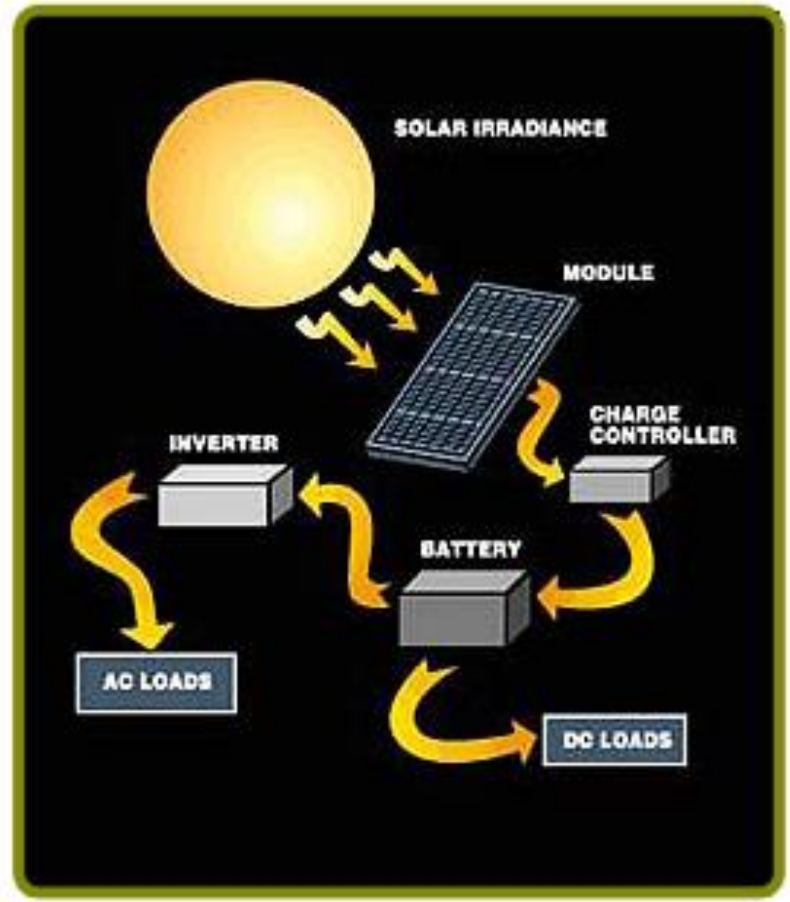


Solar Heating panels

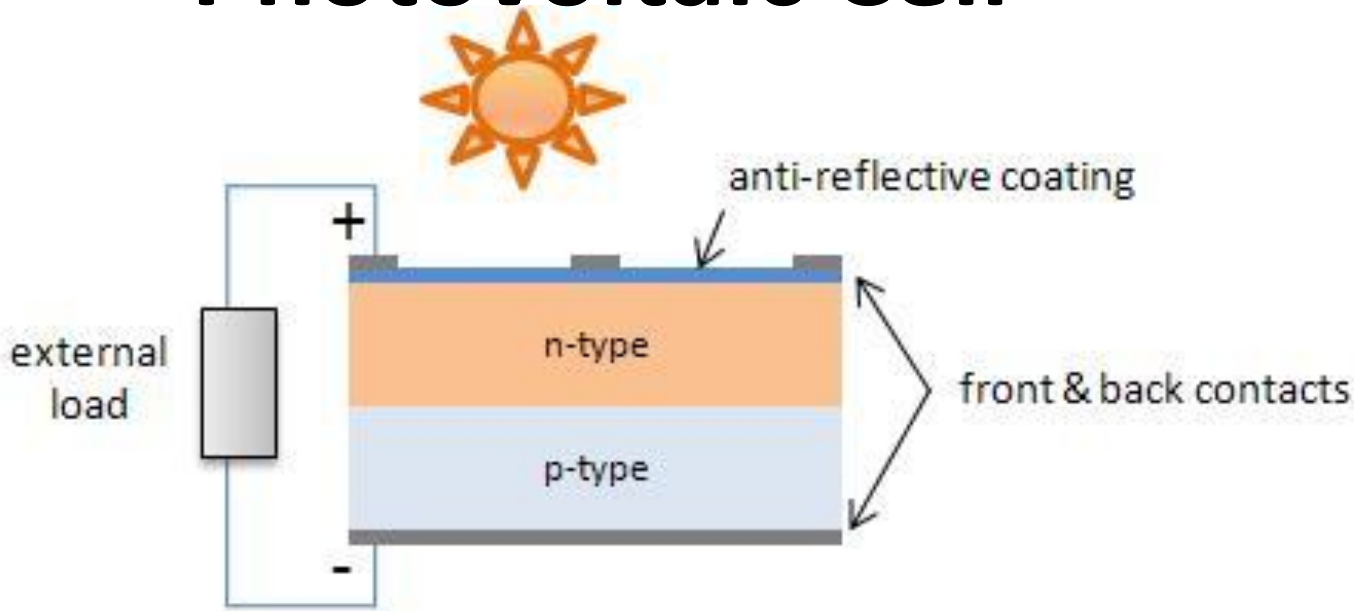
- A pump is needed because the glycol-water mixture becomes less dense as it heats up and would move to the tops of the panel and not heat the water in the cylinder.
- A controller unit is required to prevent the system pumping hot water from the cylinder to the panel during winter, when the panel is cold.

Photovoltaic Cell

- Converts a portion of the radiated energy directly into a potential difference (voltage)
- Uses a piece of semiconductor to do this
- Solar Energy $\xrightarrow{\text{photocell}}$ Electrical Energy



Photovoltaic Cell



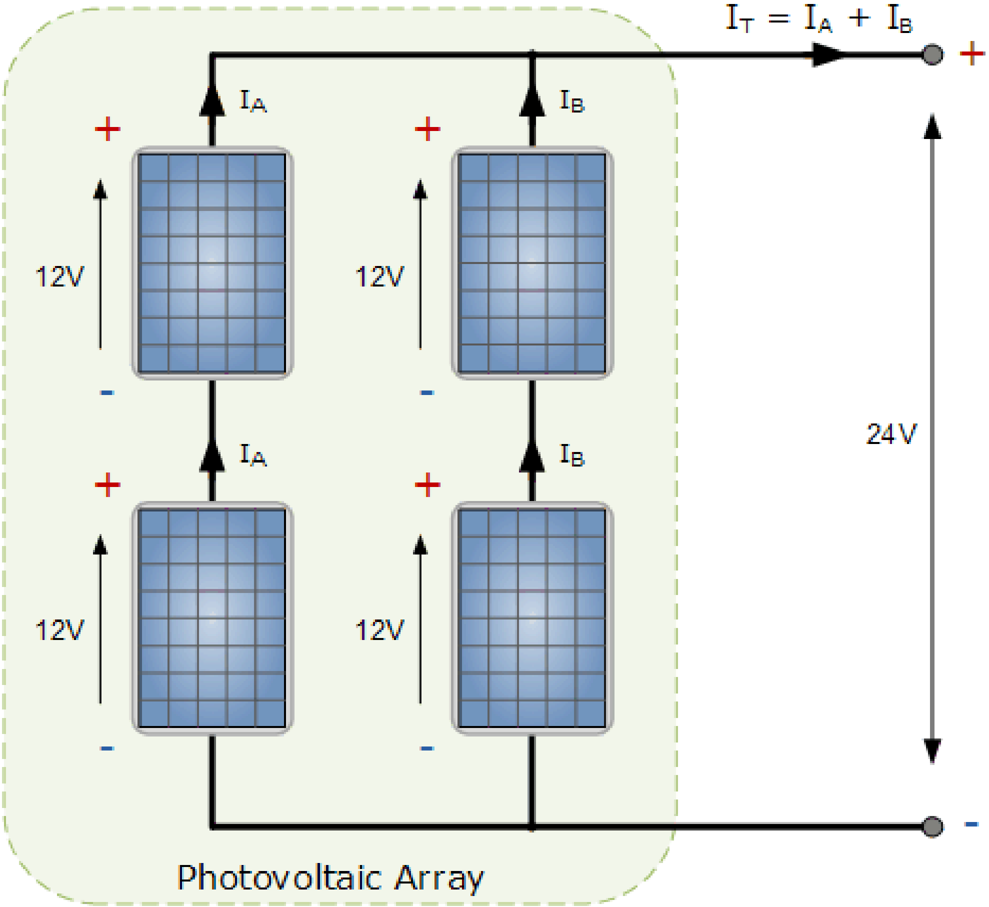
- The cell consist of a single crystal of semiconductor that is doped so that one side is p-type semiconductor and the opposite is n-type.
  - p-type: also known as positive "hole" , an absence of electrons
  - n-type: most significant charge carriers is electrons.

Photovoltaic Cell

- Normally there is an equilibrium between the charges in both halves of the cell.
- When energy in the form of photons (solar energy) falls on the cell, 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 to do useful work.

Photovoltaic Cell

- A typical photovoltaic cell produces a very small voltage and it is not able to provide much current
- Used to run electrical devices that do not require a great deal of energy
  - Calculators, watches etc.



- Using them in series will generate higher voltages but increases the internal resistances; the compromise is to connect the cells in a combination of both series and parallel.

Solar heating panels and Photovoltaic cells

Advantages

- Very ‘clean’ production
  - no harmful chemical by-products
- Renewable source of energy
- Source of energy is free/no fuel costs
- Maintenance costs are low.
- Individual households can use them

Solar heating panels and Photovoltaic cells

Disadvantages

- High initial setup cost.
- Can only be utilised during the day.
- The source and output of energy is unreliable
  - could be cloudy day.
- Low energy density and relatively large inefficiencies
  - A very large area would be needed for a significant amount of energy.

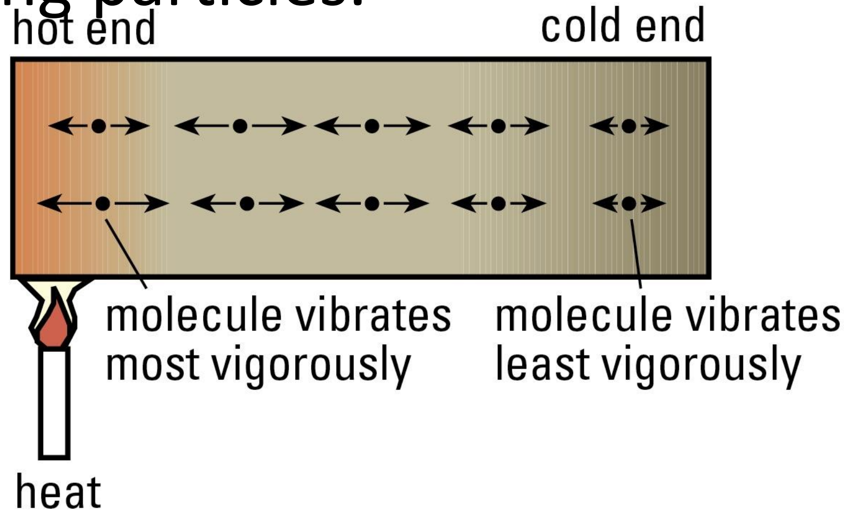
8.2 Thermal energy transfer

- Thermal energy is transferred only when there is a difference in temperature.
- Thermal energy always flows from a region of higher temperature to a region of lower temperature.
- Thermal energy is transferred by:
  - Conduction
  - Convection
  - Radiation

Thermal Conduction

Atomic vibration (For all media – solid, liquid and gas)

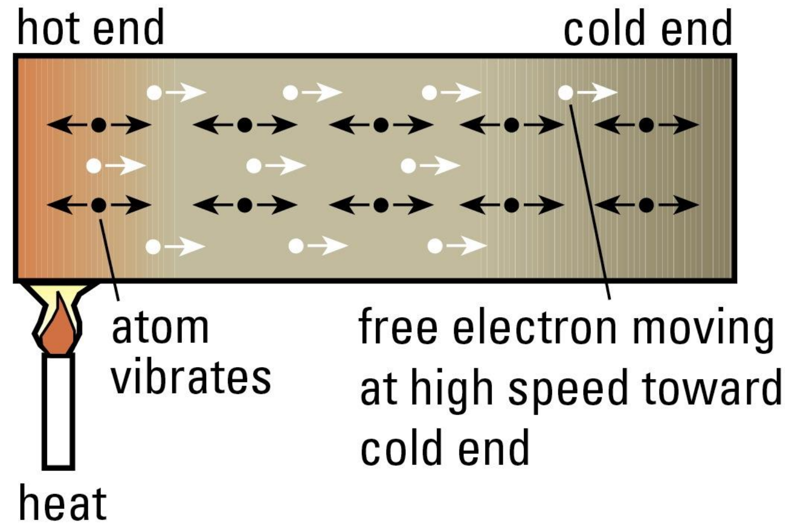
1. When thermal energy is supplied to one end of a rod, the particles (atoms and molecules) at the hot end vibrate vigorously.
2. These particles collide with neighboring particles, making them vibrate as well.
3. Kinetic energy of vibrating particles at the hot end is transferred to neighboring particles.



Thermal Conduction

Free electron diffusion (For good conductors/metal only)

- In metals, another much faster mechanism of thermal energy transfer takes place at the same time -*free electron diffusion*.
- The free electrons gain kinetic energy and move faster.
- The fast-moving electrons then diffuse into cooler parts of the metal.



Thermal Conduction

Conduction in liquids and gases

- Thermal energy can be conducted from a hotter to a cooler region.
- Process of conduction is inefficient. This is because
  1. Liquid particles are further apart and collisions of particles are less frequent and even lesser in gases.
  2. Thus, transfer of kinetic energy from fast-moving molecules to neighboring molecules is slower.

- Hence air is poor conductor of heat compared to water, which is in turn is a poor conductor compared to most solids.

Convection

How does convection work?

- When fluids (liquids and gases) are heated, they expand and become less dense.
- The less dense fluids tend to rise from the heating source.
- Cooler fluids, being more dense, sink to replace the less dense fluids.
- This movement of fluid due to a difference in its density sets up a convection current.

Convection

- Convection currents occur **only in fluids** such as liquids and gases but not in solids.
- Convection involves the **bulk movement of the fluids** which carry with them thermal energy.

Thermal Radiation

- Thermal radiation is the continual emission of infrared waves from the surface of all bodies, transmitted without the aid of a medium.
- Thermal radiation is the transfer of energy by means of electromagnetic radiation.
- Radiation does not require a medium for energy transfer. It can take place in vacuum
- The intensity of the radiation is dependent on the body's temperature. The hotter the object, the greater the radiant heat emitted.

Notes on radiation

- All objects with a temperature above 0 K radiate electromagnetic waves, usual in the infra-red spectrum.
- If an object is at constant temperature (and not changing state) then the rates of absorption and radiation of energy are the same.
- A good radiating surface is also a good absorbing surface.
- Light-coloured and smooth (shiny) surfaces are poor radiators and absorbers
- Dark and rough surfaces are good radiators and absorbers
- As the object's temperature increases the frequency of the radiation increases. The rate at which energy is radiated also increases.
- Radiation can travel through a vacuum.

Black-body radiation

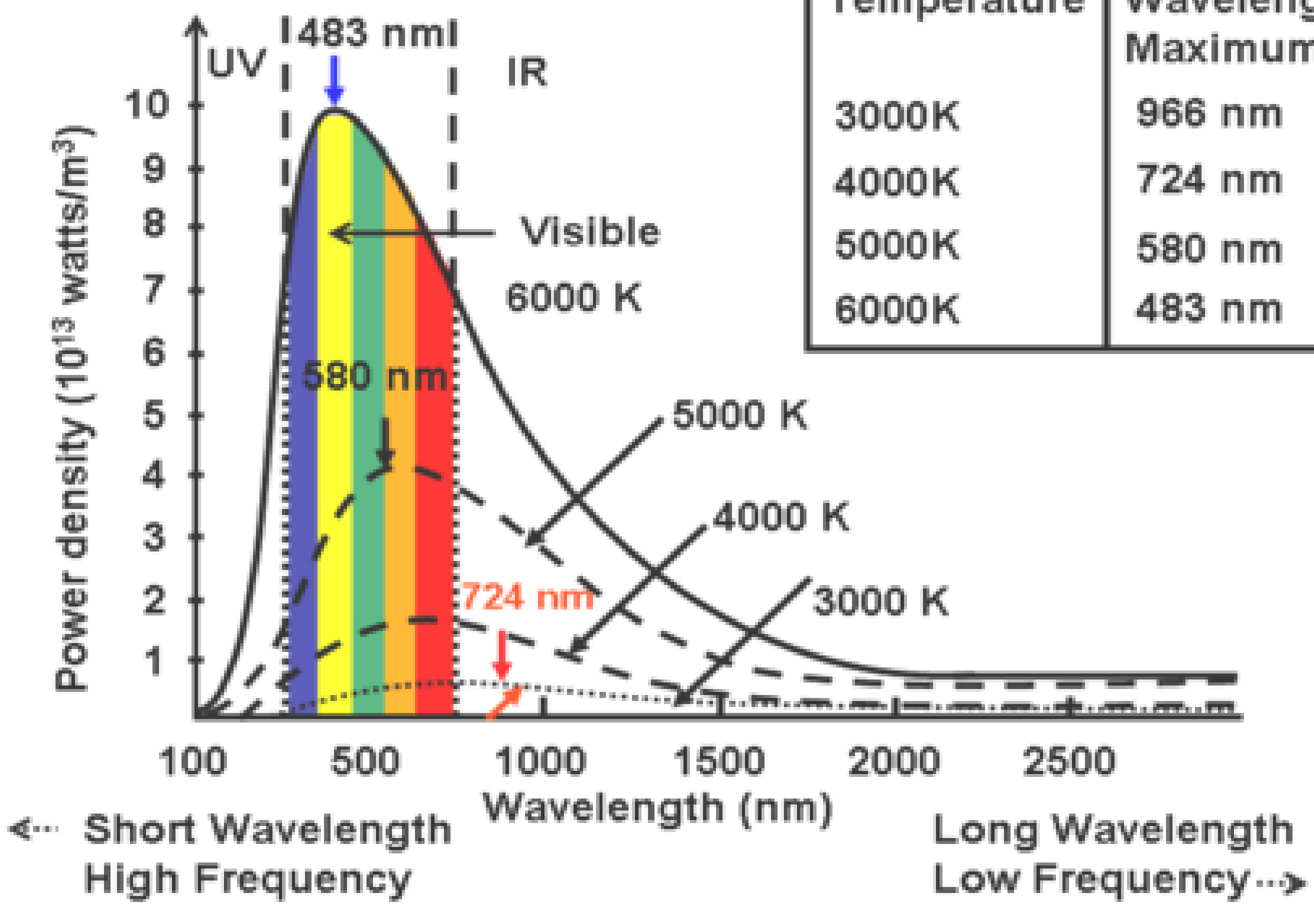
- A theoretical model for the ‘perfect’ emitter (and absorber) of radiation is known as black-body radiation.

- Black-body radiation does not depend on the nature of the emitting surface, but upon its temperature.

- At any given temperature there will be a range of different wavelengths of radiation that are emitted. At low temperatures, the radiation is in the infra-red region but as temperatures increase, the color emitted is first red, then yellow, eventually become white when temperature is high enough.

- Some wavelengths will be more intense than others.

Black-body radiation



Temperature	Wavelength for Maximum Intensity	
3000K	966 nm	(IR)
4000K	724 nm	(Red)
5000K	580 nm	(Yellow)
6000K	483 nm	(Blue)

Fig. Spectral intensity distribution of Blackbody Radiation vs Wavelength Intensity Maximum shifts to shorter wavelengths as temperature increases.

Black-body radiation

- The total area under the graph is a measure of the total power radiated.
- Stars and planets are not perfect emitters, but their radiation spectrum is approximately the same as black-body radiation.

Wien's displacement Law

- Wien's displacement law relates the **wavelength** at which the radiation **intensity is a maximum** (λ_{max}) to the **temperature** (*T*) of the black body.

$$\lambda_{\max} T = \text{constant}$$

- The value of the constant can be found by experiment to be **2.9 x 10^{-3} m K**

Wien's displacement Law

- Light from a star can be analysed to calculate a value for its surface temperature.

The peak wavelength from the Sun is approximately 500 nm.

$$\lambda_{max} = 500\ nm$$

$$\lambda_{\mathrm{max}} T = 2.9\ \times 10^{-3}\ \text{m K}$$

so $T = \frac{2.9 \times 10^{-3}}{500 \times 10^{-9}} = 5800$ K

Stefan-Boltzmann Law

- The Stefan-Boltzmann law links the **total power radiated** by a black body (per unit area) to the **temperature** of the black-body.
  <u>Total power radiated $\propto T^4$</u>

$$\text{Total power radiated} = \mathrm{e}\sigma A T^4$$

where

σ is the Stefan-Boltzmann constant. $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

A is the surface area of the emitter (m^2)

T is the absolute temperature of the emitter (K)

e is the emissivity of the surface (e=1 for black body)

Stefan-Boltzmann Law

- In practice, objects can be very close to a black body in behavior but not quite 100% in the way they behave. They are often called grey objects.
- A grey object emit less energy per second as compared to a perfect black body of the same dimensions at the same temperature.
- A perfect black body has an emissivity value of 1 and an object that completely reflects radiation without any absorption at al has an emissivity value of 0.

Stefan-Boltzmann Law

- All real object have an emissivity value between 0 and 1.
- Emissivity, *e*, is define as an ratio of power radiated by an object to the power radiated by a black body of same dimensions at the same temperature

$$e = \frac{\text{power radiated by object}}{\text{power radiated by black body at the same temperature}}$$

Stefan-Boltzmann Law

- For perfect black body e.g. the Sun (*e* = 1),

$$P = e\sigma AT^4 \Rightarrow \text{Total power radiated} = \sigma AT^4$$

The radius of the Sun = 6.96×10^8 m

Surface area = $4\pi r^2 = 6.09 \times 10^{18}$ m^2

If temperature = 5800 K

then total power radiated

$$= \sigma AT^4$$
$$= 5.67 \times 10^{-8} \times 6.09 \times 10^{18} \times 5800^4$$
$$= 3.9 \times 10^{26}\ \text{W}$$

Sun and Solar Constant

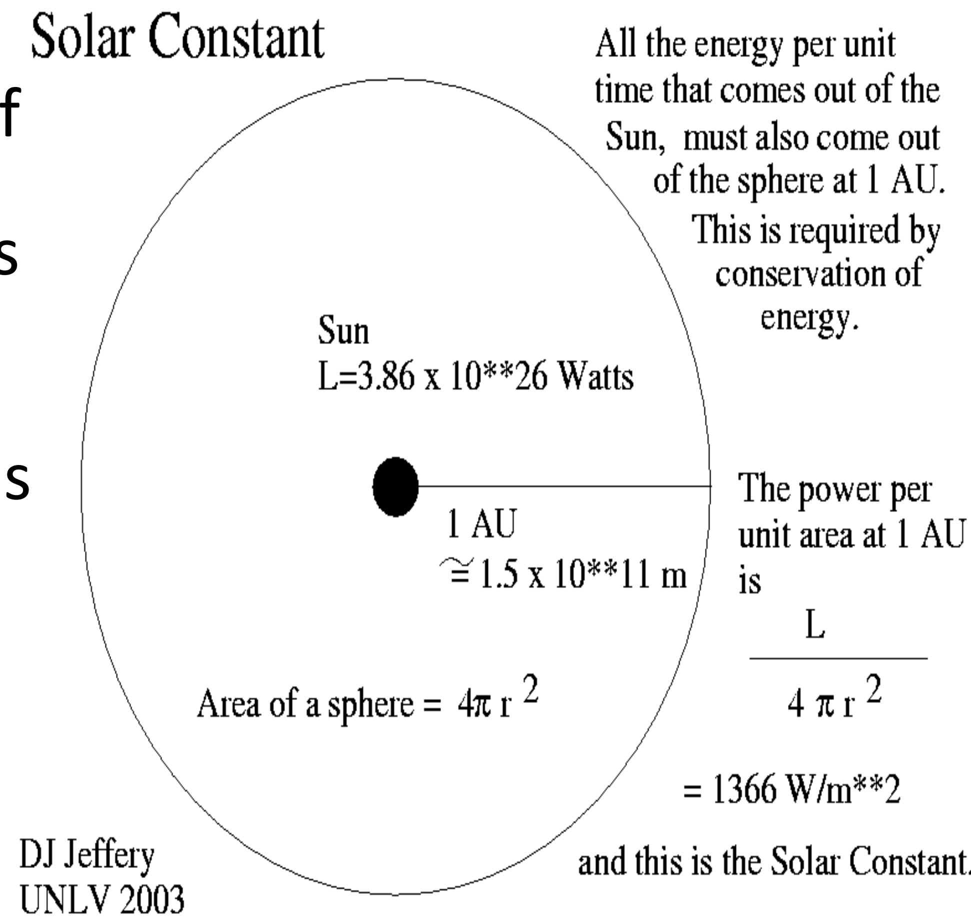
- The amount of energy that arrives at the top of the atmosphere is known as the solar constant.
- Solar constant is defined as the amount of solar radiation across all wavelength that is incident in one second on one square metre, at the mean distance of the Earth from the Sun on a plane perpendicular to the line joining the centre of the Sun and the centre of the Earth.
- Average value = 1400 W m^{-2}

Sun and Solar Constant

- The solar constant is not the same as the power that arrives on 1 m^2 of the Earth's surface
- Scattering and absorption in the atmosphere means that often less than half of energy arrives at the Earth's surface.
- The amount that arrives depends greatly output of the Sun, the weather conditions on Earth and distance between the Sun and Earth (due to Earth's elliptical orbit).

Sun and Solar Constant

- Different parts of the Earth's surface (regions of different latitude) will receive different amounts of solar radiation
- The amount received will also vary with the seasons since this will affect how spread out the rays become



Albedo

- Some of the radiation received by a planet is reflected straight back into space.

- The fraction that is reflected back is called **albedo**, *a.*

$$a = \frac{\text{energy reflected by a given surface in a given time}}{\text{total energy incident on the surface in the same time}}$$

- Like emissivity, albedo has no units, it varies from 0 for a surface that does not reflect any energy (a black body to 1 for a surface that absorbs no radiation at all.

Albedo

- Earth's albedo varies daily. Factors that affect albedo:
  - season (cloud formations)
  - latitude
  - surface type (oceans have low albedo, snow has high albedo)

- The global annual mean albedo is 0.30 – 0.35 (30% – 35%) on Earth.

Albedo

- Average mean energy level falls on each square of the upper atmosphere each second is 1400J (Solar constant =1400 Wm^{-2})

- The incoming radiation (from the Sun) falls on the portion of the Earth's surface which is normal to the Sun's radiation (Area = πr^2).

Albedo

- However, this radiation has to be averaged over the whole Earth's surface (Area = $4\pi r^2$). Thus average mean power arriving at each square metre is

$$\frac{Power}{Area} = \frac{Power}{4\pi r^2} = \frac{1}{4}\left(\frac{Power}{\pi r^2}\right) = \frac{1}{4}(1500) = 350\ Wm^{-2}$$

- Factoring albedo, the mean power absorbed by Earth Surface at $1m^2$ is

$$P=(1-a)(350W) = 245W$$

The greenhouse effect

- Short wavelength radiation is received from the sun and causes the surface of the Earth to warm up.
- The Earth will emit infra-red radiation (long wavelength radiation) because the Earth is cooler than the Sun.
- Some of the infra-red radiation is absorbed by greenhouse gases in the atmosphere and re-radiated in all directions.
- This is known as the greenhouse effect.

Greenhouse gases

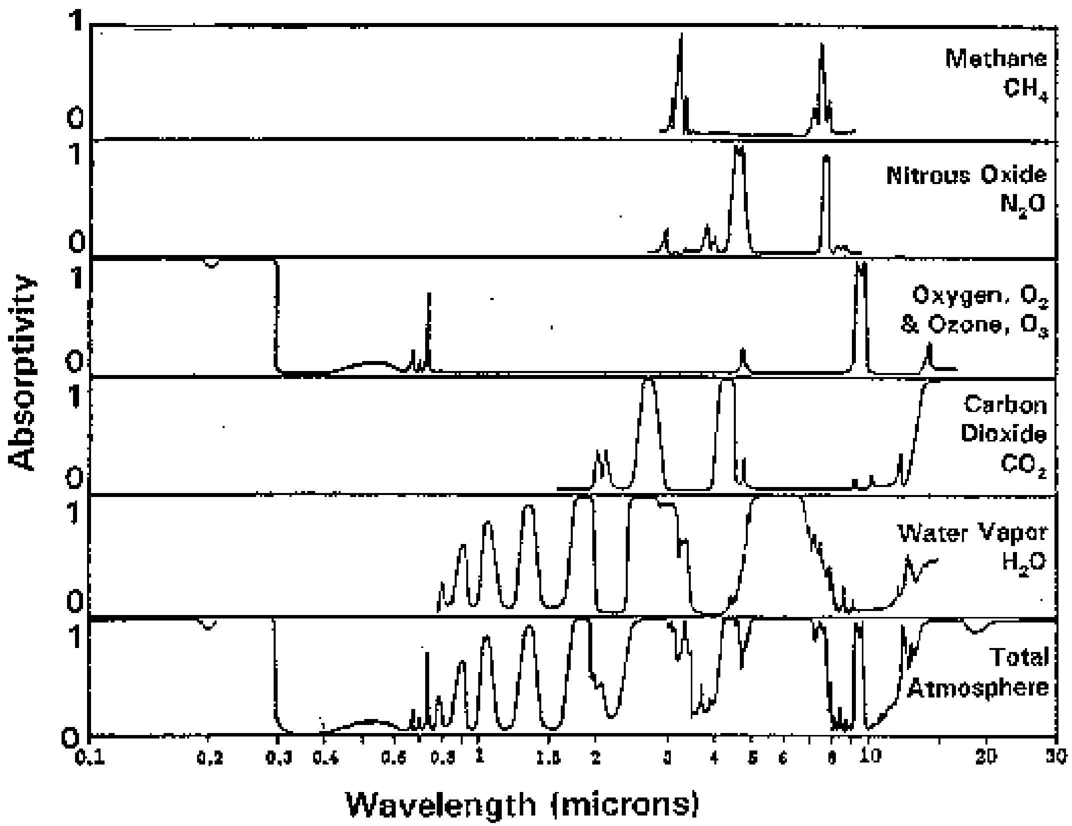
Greenhouse gas	**Source**
Methane	Natural gas. Result of decay, decomposition and fermentation. Livestock and plants.
Water vapour	
Carbon dioxide	Combustion.
Nitrous oxide	Livestock and industries (eg. producing Nylon).
Ozone	The ozone layer absorbs harmful high energy UV photons but also adds to the greenhouse effect.
Chlorofluorocarbons (CFCs)	Used as refrigerants, propellants and cleaning solvents. They also can deplete the ozone layer.

The greenhouse gases and resonance

- Greenhouse gases absorb infra-red radiation as a result of resonance.
- The natural frequency of oscillation of the bonds within molecules of the gases corresponds to the frequency of infra-red radiation.
- Hence when infra-red radiation passes through the atmosphere, resonance occurs.
- The amplitude of the molecules' vibrations increases and hence the temperature increases.

Greenhouse gas absorption spectra

ABSORPTION SPECTRA FOR MAJOR NATURAL GREENHOUSE GASES IN THE EARTH'S ATMOSPHERE



[After J. N. Howard, 1959: *Proc. I.R.E. 47,* 1459; and R. M. Goody and G. D. Robinson, 1951: *Quart. J. Roy. Meteorol. Soc. 77,* 153]

Equilibrium

- If the temperature of a planet is constant, then the power being absorbed by the planet must equal the power being radiated into space. The planet is in thermal equilibrium.
- If power absorbed > power radiated, then temperature will increase.
- If power absorbed < power radiated, then temperature will decrease.

Simple energy balance climate model

- A planet of radius *r* (m) receives a power per unit area *S* (W m^{-2}) (*S* is the solar constant). Its albedo is α (ratio; no units)

∴**Total power absorbed by the planet =** $\boldsymbol{S(1-\alpha)\pi r^2}$

- Using the Stefan-Boltzmann law and the concept of emissivity:

Total power radiated from the surface of the planet = $\boldsymbol{e\sigma 4\pi r^2 T^4}$

$$\therefore \boldsymbol{S(1-\alpha)\pi r^2 = e\sigma 4\pi r^2 T^4}$$

$$\therefore \boldsymbol{T = \sqrt[4]{\frac{S(1-\alpha)}{4e\sigma}}}$$

Example

Solar constant $S = 1380\ \text{Wm}^{-2}$ and Albedo = 0.3

Assume that no energy is absorbed by the atmosphere.

Solar intensity incident on Earth's surface when Sun is directly overhead

$= S \times (1-\alpha) = 1380 \times 0.7 = 966\ \text{Wm}^{-2}$

Earth's radius = R

Average intensity incident on the Earth's surface $= \dfrac{966 \times \pi \times R^2}{4\pi \times R^2} = 242\ \text{Wm}^{-2}$

Assume Earth behaves like a black-body ($e = 1$).

Energy balance model:

Power (intensity) absorbed = Power (intensity) radiated

$242 = \sigma T^4$

$$T = \sqrt[4]{\frac{242}{5.67 \times 10^{-8}}} = 256K$$

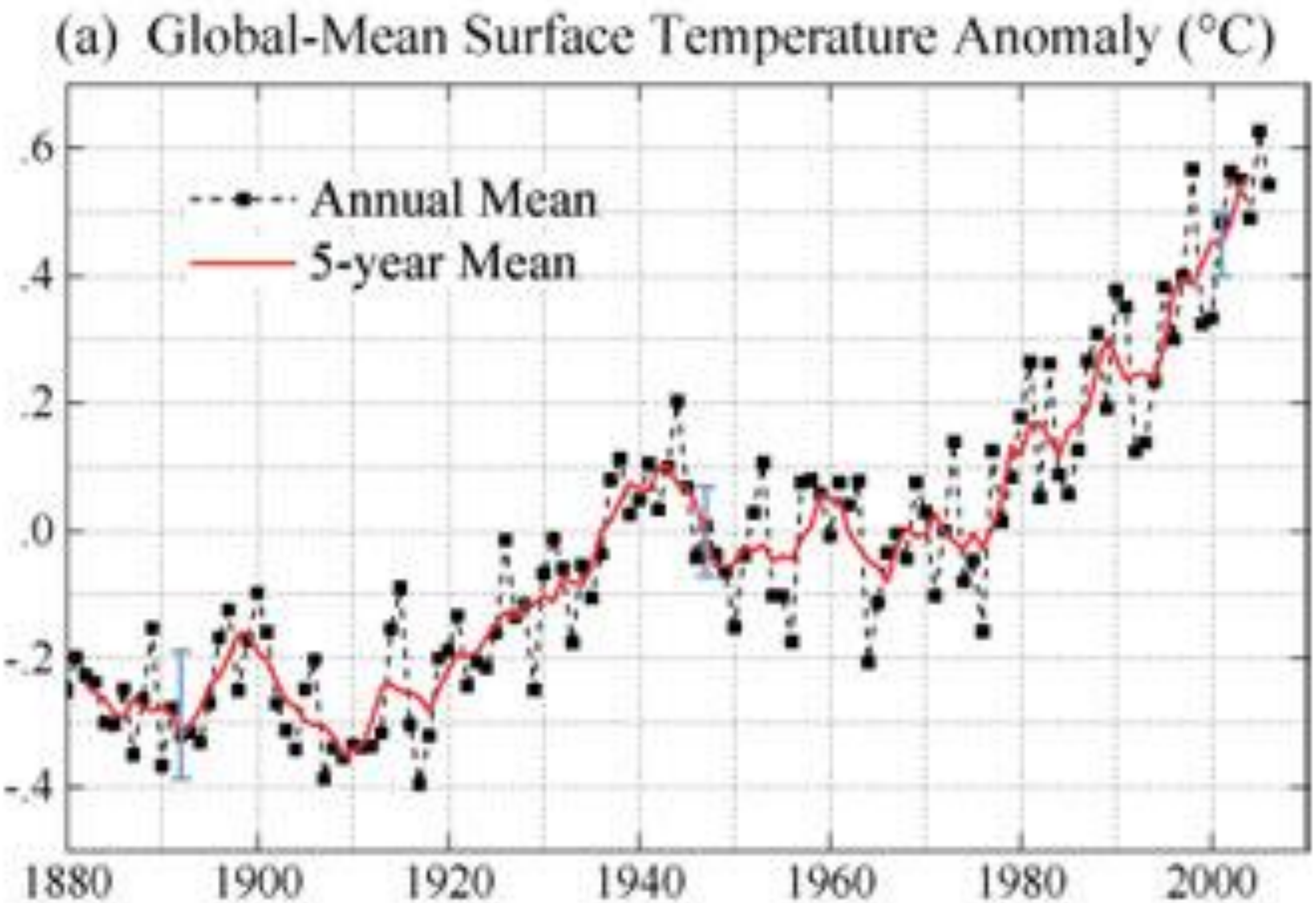
Simple energy balance climate model

This simple energy balance model allows the temperature of a planet to be predicted from the incoming radiation intensity, but contains many simplifications:

- It treats the whole planet as one single body and ignores any interactions taking place (eg. in the atmosphere/oceans)
- It ignores any processes that involve feedback (positive/negative) in which the result of a change is a further change of one of the constants involved in the calculation (eg. emissivity/albedo)
  - For example increase in temperature may melt some surface ice—causing change in albedo

Global warming

Records show that the mean temperature of the Earth has been increasing in recent years.



Possible models (causes) of global warming

Some possible suggestions for the increase include:

- Changes in the composition of greenhouse gases in the atmosphere
- Changes in the intensity of the radiation emitted by the Sun (eg. increased solar flare activity)
- Cyclical changes in the Earth's orbit and volcanic activity

Enhanced greenhouse effect

An enhanced greenhouse effect is an increase in the greenhouse effect caused by human activities.

Although it is still debated, it is generally accepted that the increased combustion of fossil fuels has released extra carbon dioxide into the atmosphere, which has enhanced the greenhouse effect.

Evidence for global warming being linked to greenhouse gases

There is evidence that links global warming to the increased levels of greenhouse gases, coming from ice core data.

- The ice core has been drilled in the Russian Antarctic base at Vostok.
- Isotopic analysis allows the temperature to be estimated and air bubbles trapped in the ice core can be used to measure the atmospheric concentrations of greenhouse gases.
- The record provides data from over 400 000 years ago to the present.
- The variations of temperature and carbon dioxide are very closely correlated.

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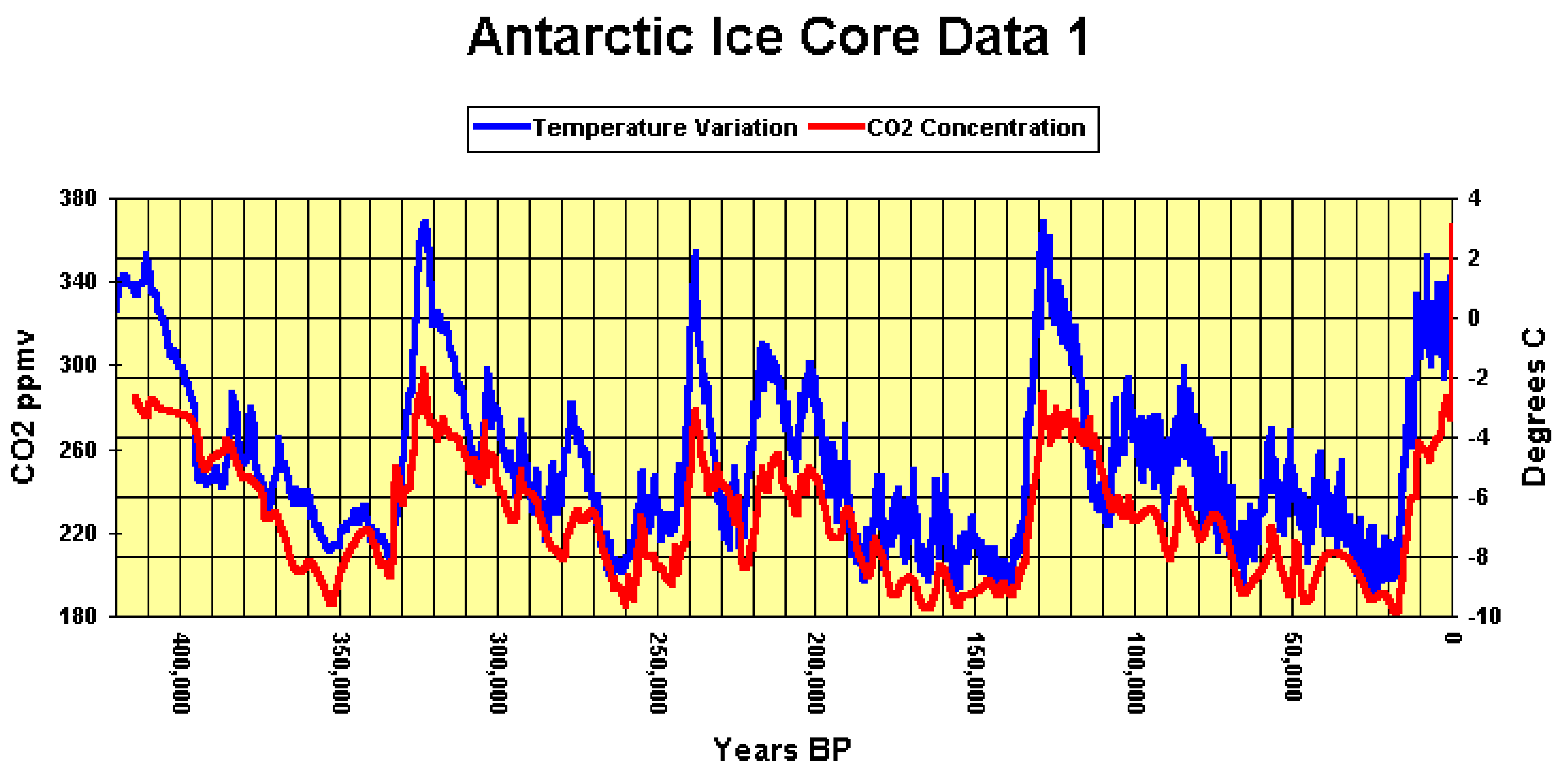

The variations of temperature and carbon dioxide are very closely correlated.

Mechanisms that may increase the rate of global warming

- Global warming reduces ice/snow cover, reducing albedo and thus increasing the overall rate of heat absorption.
- Temperature increase reduces the solubility of CO_2 in the sea and thus increases atmospheric concentrations.
- Continued global warming will increase both evaporation and the atmosphere's ability to hold water vapour, a greenhouse gas.
- Regions of frozen subsoil contain trapped CO_2. Temperature increase may cause melting and release the trapped $CO_{2.}$
- Deforestation releases CO_2 and also reduces carbon fixation (removal of CO_2 by vegetation during photosynthesis).

Mechanisms that may increase the rate of global warming

- The first four mechanisms are examples of processes whereby a small initial temperature increase has gone on to cause a further increase in temperature.
- This process is known as **positive feedback**.
- It has been suggested that current temperature increases can be ‘corrected’ by a process which involves negative feedback.

Possible solutions to reduce the enhanced greenhouse effect

- Advances in technology to ensure
  - greater efficiency of power production
  - decarbonising exhaust gases from power plants
  - fusion reactors made operational

- Reduction of energy requirements by
  - improving thermal insulation in homes and dwellings
  - reducing journeys and using more energy efficient transport eg. hybrid vehicles
  - use of combined heating and power systems (CHP).

- Replacing the use of coal and oil with renewable energy sources/nuclear power/natural gas

- Planting new trees and maintaining existing forests

International efforts to reduce the enhanced greenhouse effect

- International Panel on Climate Change (IPCC)
  - IPCC is a scientific and intergovernmental body under the UN dedicated to the task of providing the world with an objective, scientific view of climate change and its political and economic impacts. It regularly assess the up to date evidence from international research into global warming and human-induced climate change.
- Paris Agreement (2015)
  - 195 countries adopted the first-ever universal, legally binding global climate deal. This agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C. This agreement is due to enter into force in 2020. As of Aug 2016, 180 countries have signed the treaty and 22 of which ratified it.