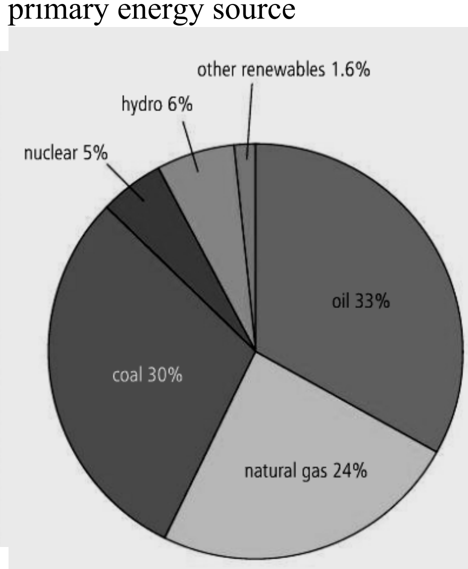
Energy Production

IB 12

Primary energy source: one that has not been transformed or converted before use by the consumer

Secondary energy source: one that results from the transformation of a primary energy source

Some primary 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



World energy use

Fossil fuels:

Origins of fossil fuels: Organic matter decomposed under conditions of high temperature and pressure over millions of years.

1. In many cases, these primary energy sources are converted into …

Non-renewable fuels: The rate of production of the fuel is much smaller than rate of usage so fuel will run out (limited supply).

Renewable fuels: A resource that cannot be used up or is replaced at same rate as it is being used.

2. Different fuels can be compared by analyzing the:

Specific Energy of a fuel: Formula: Units:

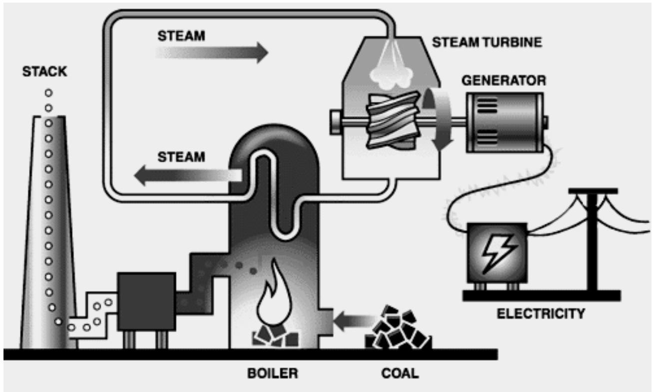
Energy Density of a fuel: Formula: Units:

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

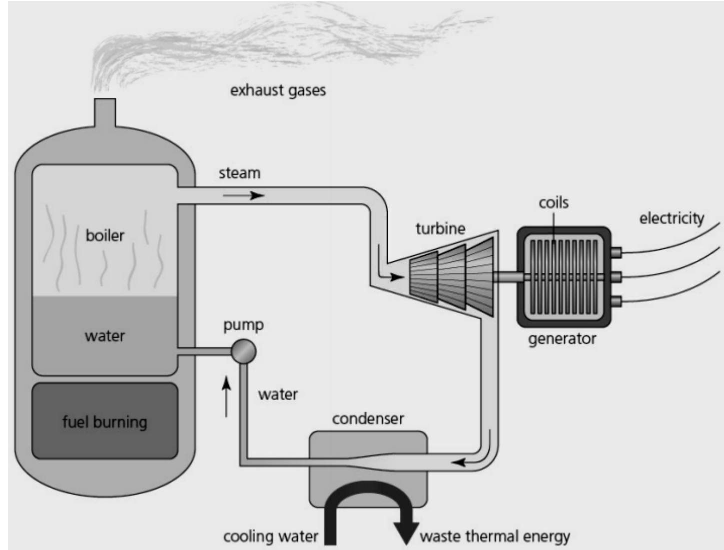
Material	Specific energy/MJkg^{-1}
nuclear fusion (of deuterium and tritium)	340000000
uranium used in nuclear reactors	83000000
hydrogen	143
natural gas (methane)	55
gasoline/petrol	46
crude oil	46
vegetable oil	42
ethanol	30
coal	28
wood	17
typical carbohydrate (food)	17
cow dung	15
household waste	9
torch battery	0.1
water at height of 100 m	0.001

3. A coal-burning power station has an efficiency of 36 per cent and an output power of 312 MW. Calculate the mass of coal burned per week.

Power Generation in a typical fossil fuel power station



schematic diagrams of a fossil-fuel power station



Features:

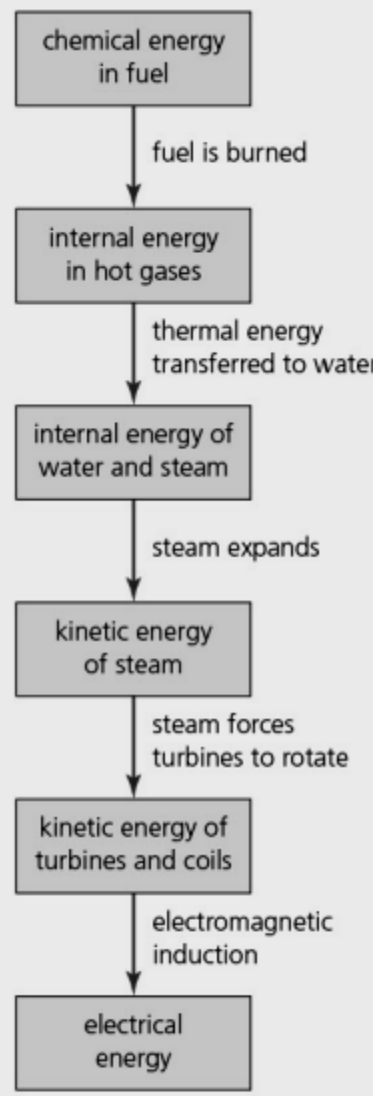
a) **Boiler:** Some fossil fuel (coal, natural gas, oil) is burned to release thermal energy which is used to boil water to make steam.

b) **Stacks:** Hot exhaust gases from the burning of the fossil fuel are vented out of stacks into the atmosphere.

c) **Generator (Dynamo)**: The steam turns turbines attached to coils of wire which turn in a magnetic field inducing an alternating potential difference.

d) **Heat exchanger (condenser):** A secondary source of water is used to cool and condense the steam back into the primary water supply to feed the boiler.

e) **Transformers:** Potential difference is stepped up by transformers for long-distance transmission (to reduce I^2R loss of power in the transmission lines).



Energy transfers in a fossil-fuel power station

Advantages and disadvantages of using fossil fuels

Advantages

- High energy density.
- Fuel is relatively cheap (although economic and political factors may result in significant and sudden changes in price).
- Power stations are relatively inexpensive to construct and maintain (when considering their high power outputs).
- Power stations can be built in almost any location (that has good transport links and a plentiful water supply).
- These are established technologies – power stations, transport and storage systems already exist.

Disadvantages

- Greenhouse gas emissions and global warming.
- Chemical pollution during mining and burning (including acid rain).
- Non-renewable sources.
- Extraction/mining can damage the environment and be hazardous to health.
- Leakage from oil tankers or pipelines can cause considerable harm to the environment.

Second Law of Thermodynamics (entropy form):

In any process, the total entropy of an isolated system (the universe) always increases.

Second Law of Thermodynamics (Clausius form):

a) Thermal energy cannot spontaneously transfer from a region of low temperature to a region of high temperature.

b) It is not possible for thermal energy to be transferred from a cold object to a hot object without work being done on it.

Second Law of Thermodynamics (Kelvin form):

No heat engine, operating in a cycle, can take in thermal energy and convert it completely into work.

Degraded energy: In any process that involves energy transformations, degraded energy is energy that is transferred to the surroundings (thermal energy) and is no longer available to perform useful work.

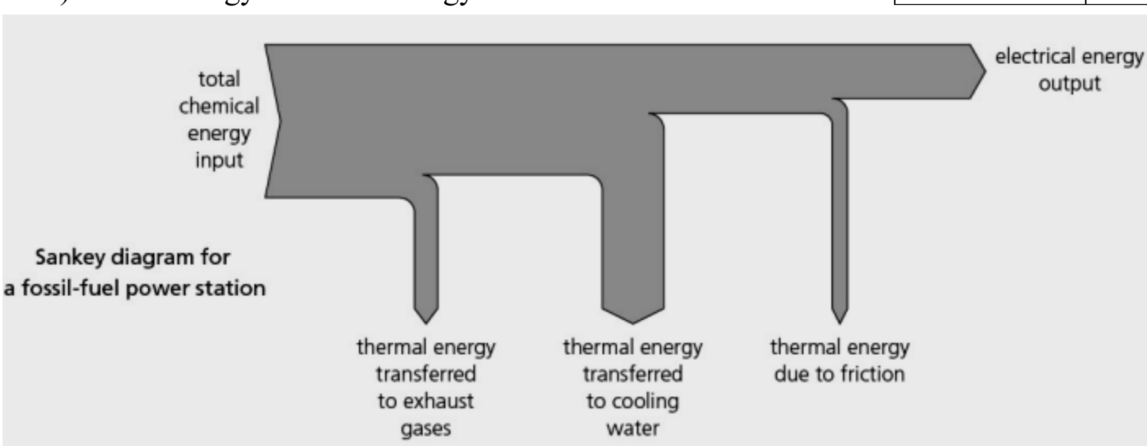
Sankey diagrams (energy flow diagrams): used to keep track of energy transfers and transformations

a) Thickness of arrow is proportional to amount of energy.

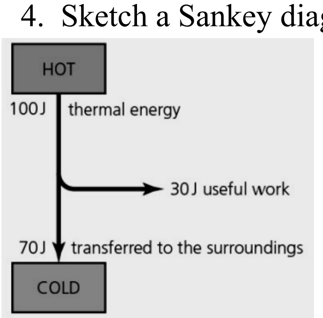
b) Degraded energy points away from main flow of energy.

c) Total energy in = total energy out.

Fuel	**Typical Efficiency**
Natural Gas	
Coal	
Oil	

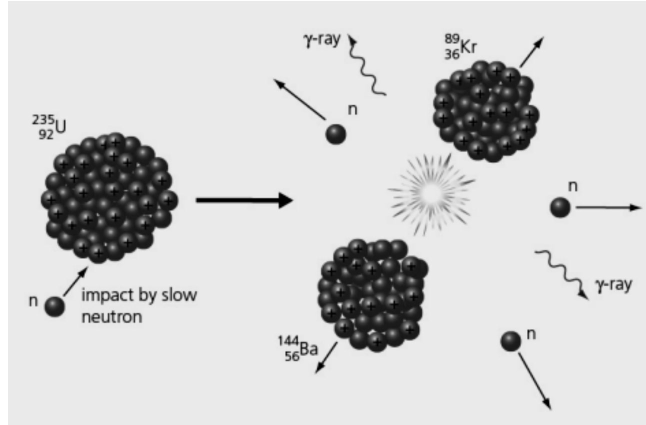


4. Sketch a Sankey diagram for the heat engine shown below and calculate the engine's efficiency.



Nuclear Energy - Fission

Process: An unstable uranium-235 nucleus is bombarded with a thermal (slow) neutron and splits into two smaller nuclei and some neutrons. The rest mass of the products is less than the reactants so some matter is converted into energy. The released neutrons strike other uranium nuclei causing further fissions.



$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^{1}_{0}n$$

In what form is the energy released?

Thermal Neutron: low-energy neutron (≈1eV) that favors fission reactions – its energy is comparable to gas particles at normal temperatures

Why use neutrons?

Naturally Occurring Isotopes of Uranium:

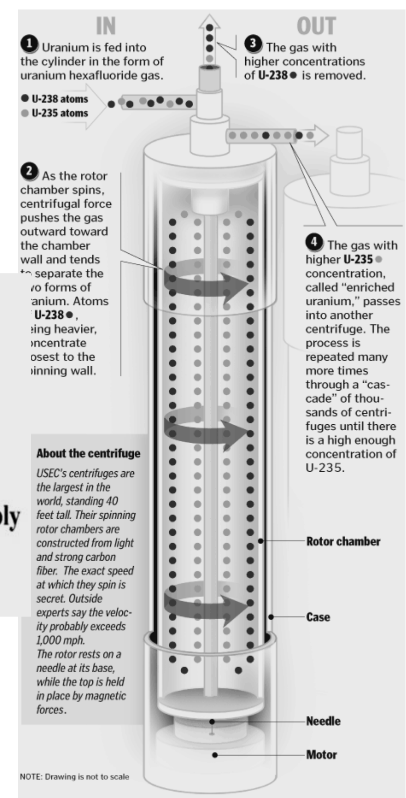
a) **Uranium-238:** most abundant (99.3%) but not used for fuel since it has a very small probability of fissioning when it captures a neutron.

b) **Uranium-235:** rare (0.7%) but used for fuel since it has a much greater probability of fissioning when captures a neutron but must be a low-energy neutron (thermal neutron).

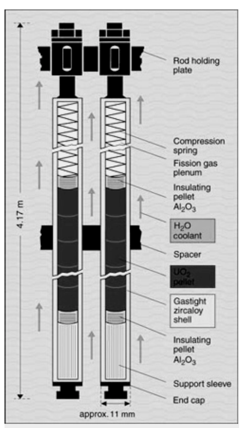
Fuel Enrichment: process of increasing the proportion of uranium-235 in a sample of uranium

Fuel-grade enrichment:

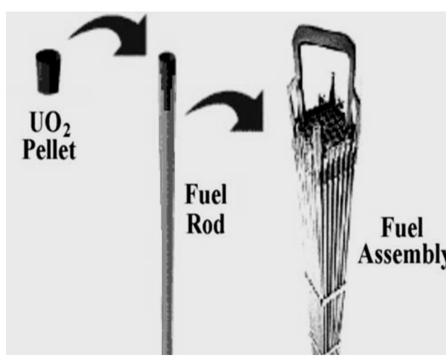
Weapons-grade enrichment:



A cascade of centrifuges used for enriching uranium

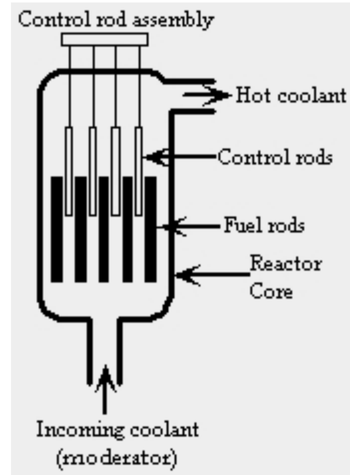


Nuclear Fuel Rods



Fuel Rods: enriched solid uranium

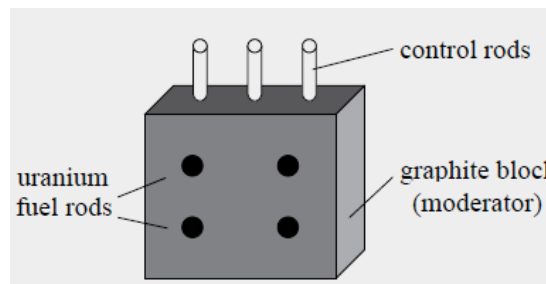
The Nuclear Reactor Core



Liquid Moderator (also acts as coolant and as fluid for heat exchanger)

When neutrons are emitted from a fission reaction in the fuel rods, they have a very high kinetic energy and will pass right out of the fuel rod without colliding with another uranium nucleus to cause more fission. High energy neutrons cannot sustain a chain reaction. Therefore, a material is needed to slow them down. Typically, a material like water or graphite (called a "**moderator**") is used to slow down these high-energy neutrons down to "thermal levels" (thermal neutrons ≈ 1 eV) for use in further fission reactions to sustain the chain reaction. The high-energy neutrons slow down when they collide with the atoms in the moderator.

Moderator: substance used to slow down neutrons to thermal levels to ensure that the fission takes place



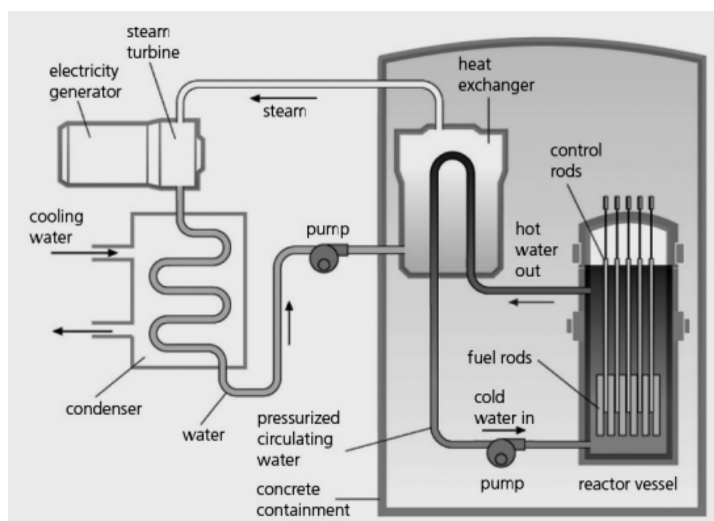
Solid Moderator

To control the rate at which the thermal energy is produced, and therefore to control the temperature of the reactor core, **control rods** are used to speed up or slow down the chain reaction. These are rods made of a neutron-absorbing substance, like cadmium or boron. They are inserted in between the fuel rods and raised or lowered as needed. If the reaction is proceeding too fast (too hot) the rods are lowered and enough thermal neutrons are absorbed to slow down the reaction to the desired level. Conversely, if the reaction is too slow, the control rods are raised allowing more thermal neutrons to collide with uranium nuclei.

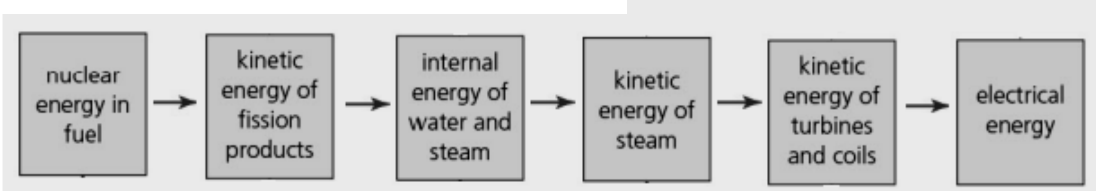
Control Rods: used to remove neutrons to control the rate of the reaction

How is the thermal energy that is released in the fission reactions used to generate electricity?

The **coolant** (which is often the same as the moderator) is fluid circulating around the fuel rods in the reactor core and is heated up by the thermal energy released in the fission chain reaction.
This coolant in a closed loop (primary loop) flows through pipes in a tank of water known as the "**heat exchanger.**" Here the thermal energy of the hot coolant is transferred to cooler water in a secondary loop which turns it to steam. This steam expands against fan blades of turbines and turns a magnet is a coil of wire to generate electricity.

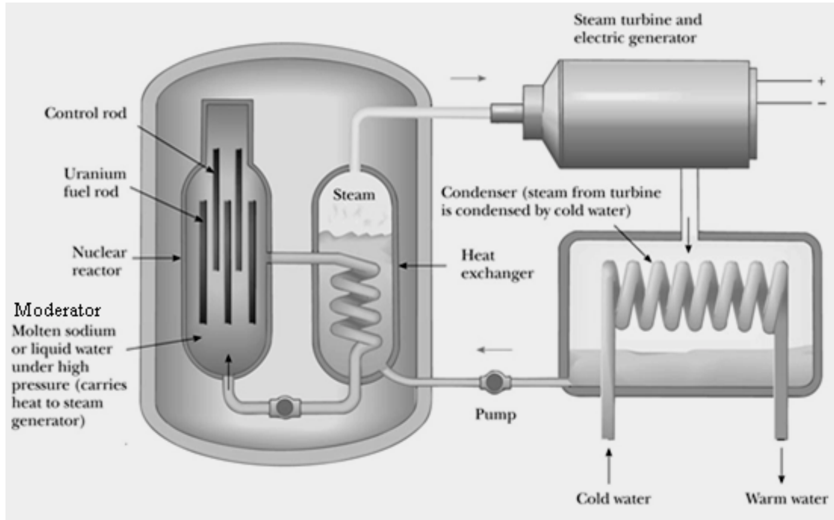


A pressurized water- cooled reactor

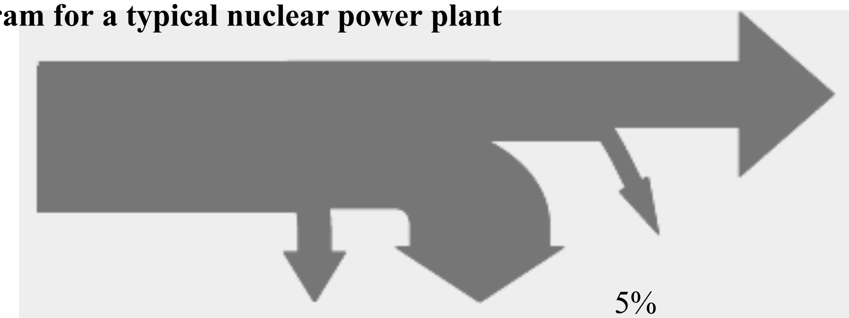


Energy flow in a nuclear power station

Main components of a pressurized-water reactor (PWR)



Sankey diagram for a typical nuclear power plant



100 %
Input energy
from nuclear fuel

30%
Useful electrical
energy output

15%
Thermal energy loss
in nuclear core

50%
Thermal
energy loss in
cooling towers

5%
Thermal energy loss
in friction of
generator and I^2R
loss in transmission
lines

Safety Issues and Risks in the Production of Nuclear Power

Uranium Mining:

- **open-cast mining:** environmental damage, radioactive waste rock (tailings)
- **underground mining:** release of radon gas (mines need ventilation), radioactive rock is dangerous for workers, radioactive waste rock (tailings)
- **leaching:** Solvents are pumped underground to dissolve the uranium and then pumped back out. This leads to contamination of groundwater.

Thermal Meltdown:

Overheating and melting of fuel rods may be caused by a malfunction in the cooling system or the pressure vessel. This overheating may cause the pressure vessel to burst sending radioactive material and steam into atmosphere (as in Chernobyl, Ukraine 1986). Hot material may melt through floor (as in Three Mile Island, Pennsylvania 1979), a scenario dubbed the "China syndrome." The damage from these possible accidents is often limited by a containment vessel and a containment building.

Nuclear Weapons Manufacture:

- Enrichment technology could be used to make weapons grade uranium (90%) rather than fuel grade (3-5%)

- Plutonium is most used isotope in nuclear weapons and can be gotten from reprocessing spent fuel rods

Nuclear Waste:

- **Low-level waste:** Radioactive material from mining, enrichment and operation of a plant must be disposed of. It's often left encased in concrete.

- **High-level waste:** a major problem is the disposal of spent fuel rods. Some isotopes have ½ lives of thousands of years. Plutonium's is 240,000 years. Some are stored under water at the reactor site for several years to cool off then sealed in steel cylinders and buried underground. Some are reprocessed to remove any plutonium and useful uranium. The remaining isotopes have shorter ½ lives and the long-term storage need is reduced.

Advantages and disadvantages of nuclear power

Advantages	Disadvantages
• Extremely high energy density. • No greenhouse gases emitted during routine operation. (Some scientists think that nuclear power may be the only realistic solution to global warming.) • No chemical pollution during operation. • Reasonably large amount of nuclear fuels are still available. • Despite a few serious incidents, statistically over the last 50 years, nuclear power has overall proven to be a reasonably safe energy technology.	• Dangerous and very long-lasting radioactive waste products. • Expensive. • Efficiency is not high when the whole process is taken into account. • Threat of serious accidents. • Possible target for terrorists. • Linked with nuclear weapons. • Not a renewable source.

1. Calculate the speed of a thermal neutron.

2. A nuclear power station using U-235 has an efficiency of 43% and a useful power output of 1 GW.

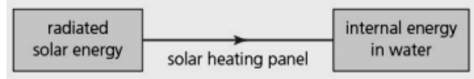
   a) If the average energy released per fission is 190 MeV, calculate how many fissions occur every second.

   b) What mass of U-235 is needed every day?

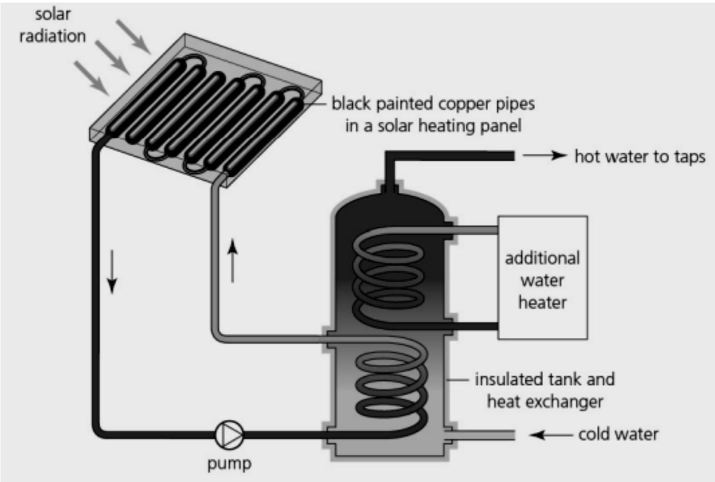
Solar Power

There are two distinctly different methods of getting energy from the Sun:

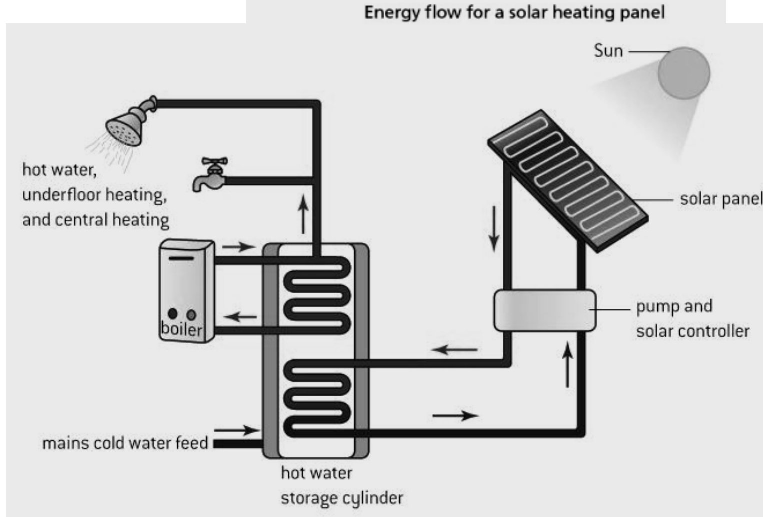
1. **Solar heating panel (active solar heater):** a panel containing pipes with a water-glycol mixture used to heat water



Energy flow for a solar heating panel



A solar heating system

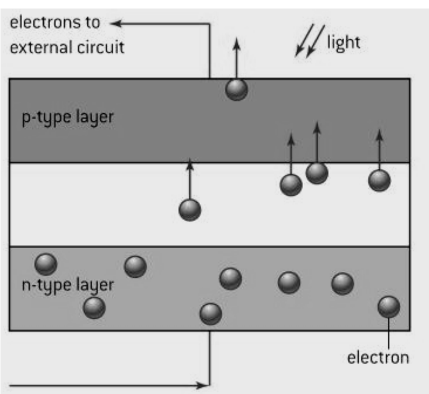


Solar thermal-domestic hot water system.

2. **Photovoltaic cell (PV cell, solar cell):** a cell of semiconductive material used to generate electricity

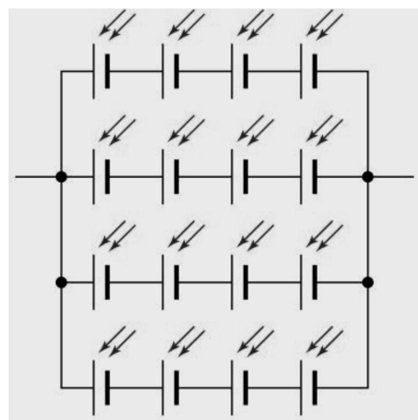
Energy flow for a photovoltaic cell

Efficiency: Operating Principle:



Cross-section of a photovoltaic cell.

Photovoltaic cells



Connecting photovoltaic cells together.

A single cell produces an emf of about . . .

Many PV cells (PV panels) are connected in combination in order to . . .

Advantages and disadvantages of solar power

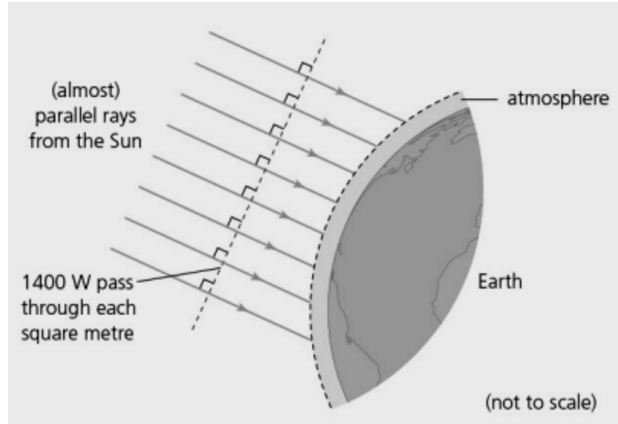
Advantages	Disadvantages
• Renewable source of energy. • Free source of energy. • Pollution-free during use. • Low maintenance costs. • Typical 20+ years' lifetime.	• Variation of output with time of day/night, weather, time of year etc. (meaning that individual systems need supplementary power/batteries). • Photovoltaic cells and solar heating panels are expensive to construct and install (but they are becoming significantly cheaper). • Photovoltaic cells have some pollution issues during construction and end-of-use recycling. • Low energy density – large areas needed for photovoltaic power stations.

Solar constant: the total radiation energy received from the Sun per unit of time per unit of area on a theoretical surface perpendicular to the Sun's rays and at Earth's mean distance from the Sun.

Value of solar constant:

Intensity:

Average value over entire surface of Earth:



Solar radiation arriving at the Earth

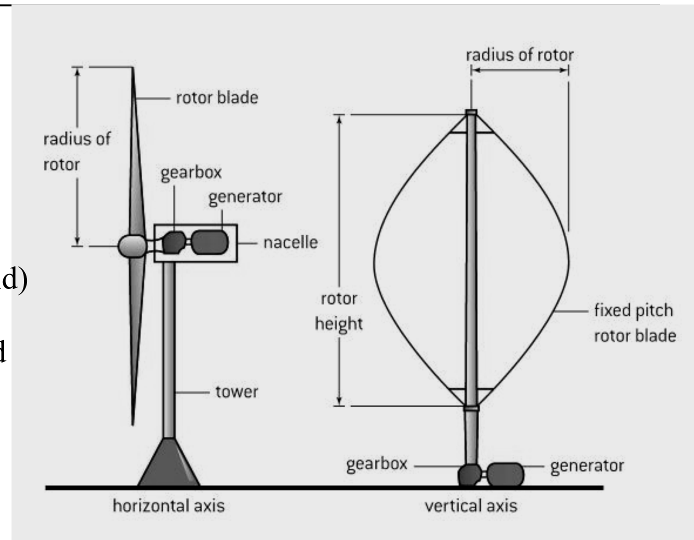
1. A photovoltaic cell with an area of 4.0 m^2 is placed in a position where the intensity of the Sun is 1.0 kW/m^2. If the cell is 15% efficient, how much power does it produce?

2. An active solar heater whose efficiency is 32% is used to heat 1400 kg of water from 20^0 C to 50^0 C. The average intensity of the Sun in that location is 0.90 kW per m^2. The specific heat of water is 4.2×10^3 J kg^{-1} K^{-1}.

   a) How much energy will be needed from the Sun to heat the water?

   b) Calculate the area of the solar heater necessary to heat the water in 2.0 hours.

Wind Power



Basic features of a wind generator/turbine:

a) Tower to support rotating blades

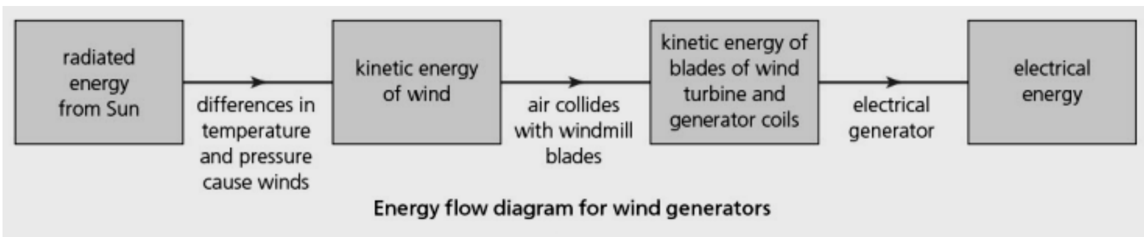
b) Blades (that may rotate to face into the wind)

c) Generator (coil of wire spinning in a magnetic field)

d) Storage system or connection to a distribution grid

The blades may rotate around a:

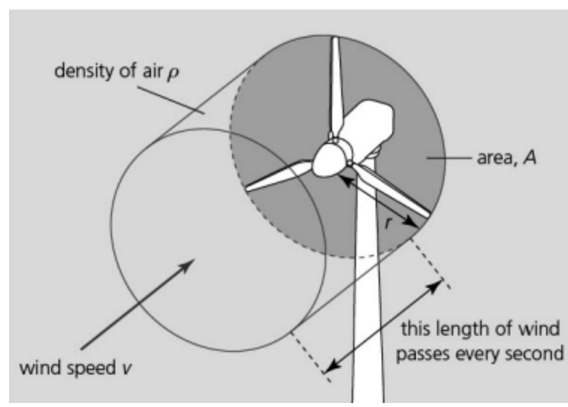
a) b)



Energy flow diagram for wind generators

Degraded energy:

Formula for Maximum Power from a Wind Generator



What are some assumptions/limitations of this formula?

a)

b)

c)

d)

Why not make blades as long as possible?

Best locations for a wind farm:

Advantages and disadvantages of wind power	
Advantages	**Disadvantages**
• No greenhouse gas emissions. • Renewable source. • Free source of energy. • No pollution during use. • Small generators are ideal for remote locations.	• Expensive to construct. • Low energy density; large area needed (although the land around them can still be used for farming). • Wind speed (and power output) is unreliable. • Emits some noise. • Best locations are often far away from cities and towns. • Many people consider that they are ugly and spoil the environment.

1. A wind turbine has a blade length of 10 m and the speed of the wind is 25 m/s on a day when the air density is 1.3 kg/m^3.

   a) Calculate the maximum power that could be produced.

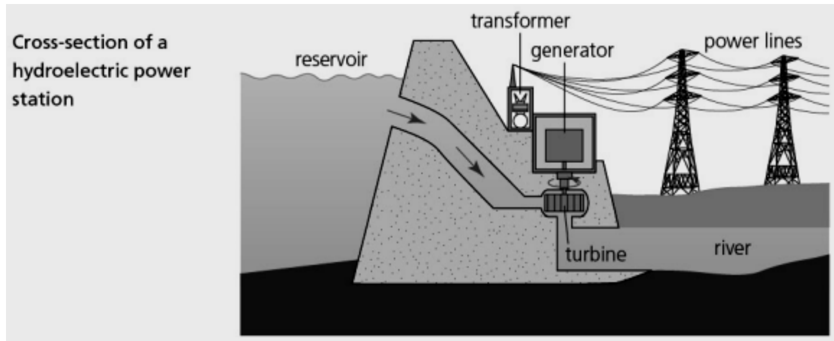
   b) Suppose the air slows to a speed of 20 m/s after hitting the fan and recalculate the power.

2. A small farmhouse needs an average power of 4 kW. A wind generator is to be placed on the top of a tower where the effective average wind speed is 7.5 m s^{-1}. Calculate the length of the blades needed to generate this power if the system is 24% efficient.

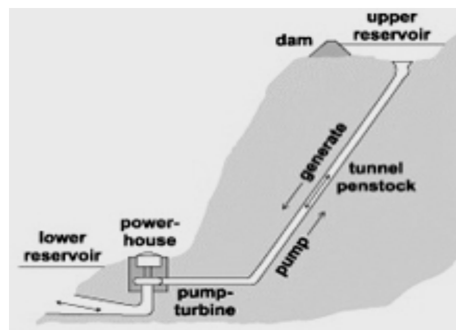
Hydroelectric Power

There are many schemes for using water to generate electrical energy. But all hydroelectric power schemes have a few things in common. Hydroelectric energy is produced by the force of falling water. The gravitational potential energy of the water is transformed into mechanical energy when the falling water moves through the rotary blades of the turbine. The turbine's rotation spins electromagnets which generate current in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines.

1. By far, the most common scheme for harnessing the original gravitational potential energy is by means of **storing water in lakes**, either natural or artificial, behind a dam.



2. A second scheme is called **pumped storage.** Water is pumped to a high reservoir during the night when the demand, and price, for electricity is low. During hours of peak demand, when the price of electricity is high, the stored water is released to produce electric power. A pumped storage hydroelectric power plant is a net consumer of energy but decreases the price of electricity.

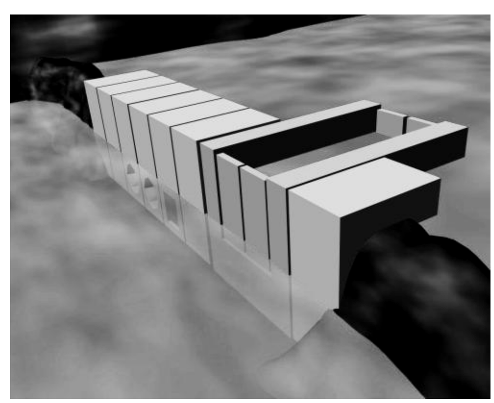


Typical pumped-storage development

3. **Tidal power**, also called **tidal energy**, is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity.

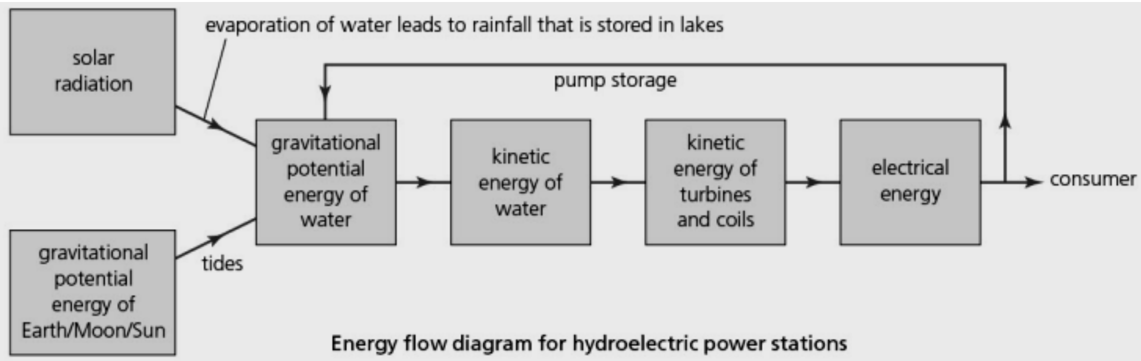
   a) Tidal stream generators make use of the kinetic energy of moving water to power turbines, in a similar way to wind turbines that use wind to power turbines. Some tidal generators can be built into the structures of existing bridges.

   b) Tidal barrages make use of the potential energy in the difference in height between high and low tides. When using tidal barrages to generate power, the potential energy from a tide is seized through strategic placement of specialized dams. When the sea level rises and the tide begins to come in, the temporary increase in tidal power is channeled into a large basin behind the dam, holding a large amount of potential energy. With the receding tide, this energy is then converted into mechanical energy as the water is released through large turbines that create electrical power through the use of generators. Barrages are essentially dams across the full width of a tidal estuary.



4. **Run-of-the-river hydroelectricity** (**ROR**) is a type of hydroelectric generation plant whereby little or no water storage is provided. ROR projects are dramatically different in design and appearance from conventional hydroelectric projects. Traditional hydro dams store enormous quantities of water in reservoirs, sometimes flooding large tracts of land. In contrast, run-of-river projects do not have most of the disadvantages associated with dams and reservoirs, which is why they are often considered environmentally friendly.


A run-of-the-river plant in Canada.

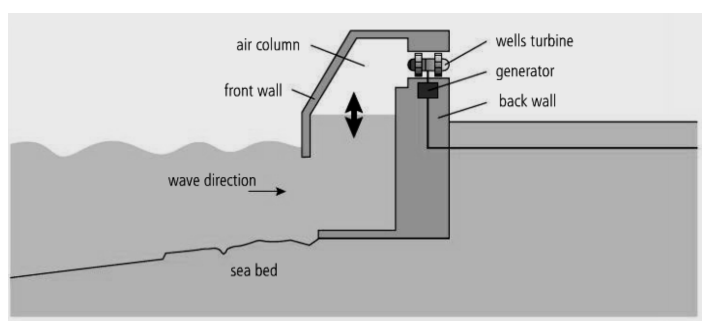


Energy flow diagram for hydroelectric power stations

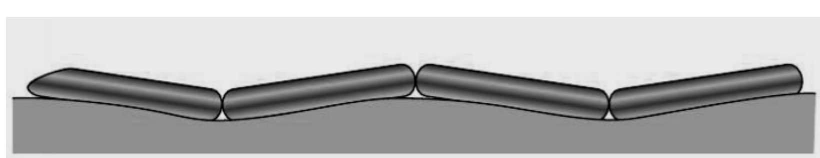
Advantages and disadvantages of hydroelectric power

Advantages	Disadvantages
• Renewable source of energy.	• The environment will be affected and the natural habitat of many plants and animals may be destroyed.
• No greenhouse gas emissions (although there will probably be some increase in the release of methane from the enlarged lakes).	• Newly built dams will form lakes that may cover land that was previously villages, towns, farmland etc.
• Relatively high efficiency.	• Can only be used in certain locations (mountainous/hilly places).
• Free source of energy.	• Large-scale projects can be very expensive to construct, although maintenance is more reasonable.
• No significant pollution during operation.	• The natural flow of rivers may be interrupted, which can have many undesirable consequences.
• Dams may also be used to control river flow, improve irrigation and prevent flooding.	• Hydroelectric power stations may be a long way from centres of population, so the power may need to be transmitted over long distances.
• Newly created lakes can be a recreational resource and provide a new habitat for some plants and animals.	• If a dam bursts it can cause considerable damage and loss of life.
• Can be the ideal energy resource for remote, hilly locations.	

5. **Oscillating water column** devices can be located on shore or in deeper waters offshore. With an air chamber integrated into the device, swells compress air in the chambers forcing air through an air turbine to create electricity. Significant noise is produced as air is pushed through the turbines, potentially affecting birds and other marine organisms within the vicinity of the device. There is also concern about marine organisms getting trapped or entangled within the air chambers.

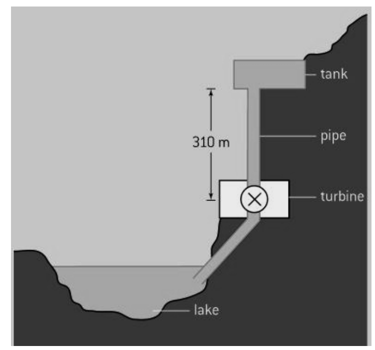


6. The **Pelamis Wave Energy Converter** is a technology that uses the motion of ocean surface waves to create electricity. The machine is made up of connected sections which flex and bend as waves pass; it is this motion which is used to generate electricity.



1. What is the average power output from a small hydroelectric power station operating at 92% efficiency if 242,000 kg of water passes through its turbines every hour, having fallen a distance of 82.4 m?

2. The diagram shows a pumped storage power station used for the generation of electrical energy. Water stored in the tank falls through a pipe to a lake through a turbine that is connected to a generator. The tank is 50 m deep and has a uniform area of 5.0×10^4 m^2. The height from the bottom of the tank to the turbine is 310 m. The density of water is 1000 kg/m^3.



a) Show that the maximum energy that can be delivered to the turbine by the falling water is about 8×10^{12} J.

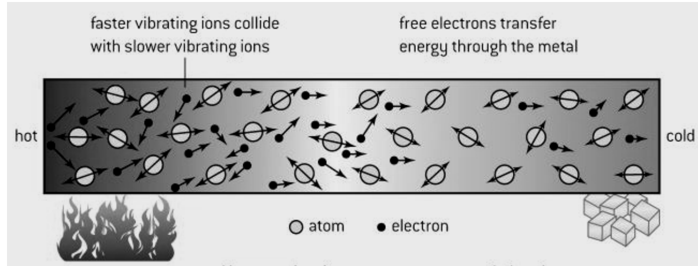
b) The flow rate of water in the pipe is 400 m^3 s^{-1}. Calculate the power delivered by the falling water.

3. In a tidal barrage system water is retained behind a dam of height *h*. Show that the gravitational potential energy available from the water stored behind the dam is proportional to h^2.

Principal Methods of Thermal Energy Transfer

I. Thermal Conduction:

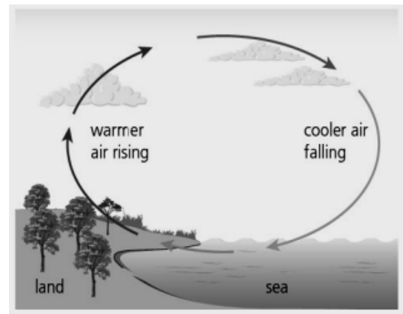
In conduction processes, energy flows through the bulk of the material without any large-scale relative movement of the particles (atoms/molecules) that make up the object. Faster moving particles collide with slower moving ones and transfer energy during the collisions. Conduction is primarily of importance in solids and less so in liquids and gases where the particles are further apart.



How conduction occurs at an atomic level.

II. Convection:

Convection is the bulk movement of groups of particles within fluids (liquids and gases) due to variations in density. Hotter less-dense fluid rises and cooler more-dense fluid falls to take its place. This is known as a convection current (cycle).

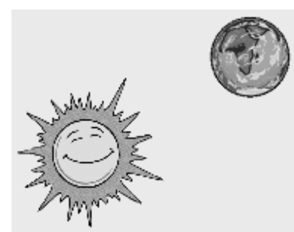


Convection currents near the beach during the day

	Solids	Liquids	Gases
Conduction			
Convection			

III. Radiation:

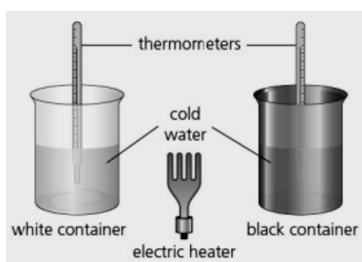
Thermal radiation is the transfer of energy by means of electromagnetic radiation. It has its origins in the thermal motion of the charged particles of the object that emit photons as they move and are accelerated. Radiation from the Sun reaches Earth across the vacuum of space.



Dark/black objects are better **absorbers** of radiation than light/white and shiny objects.

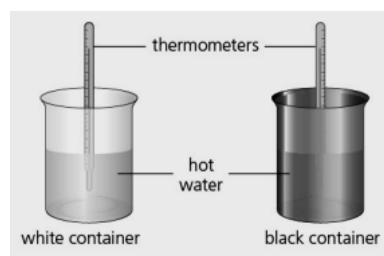
Dark/black objects are better **emitters** of radiation than light/white and shiny objects.

Absorption of Radiation



Comparing thermal radiation gains

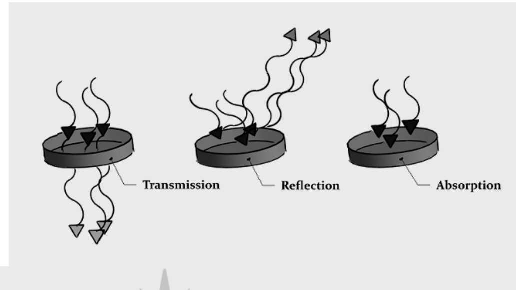
Emission of Radiation



Comparing thermal radiation losses

1. In the two experiments pictured above, which thermometer changes the fastest?

2. When incoming light (radiation) strikes an object, it will undergo . .

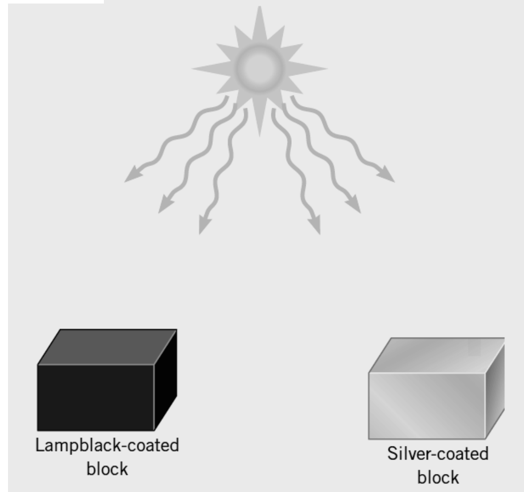


   a)

   b)

   c)

3. Notice that . . .

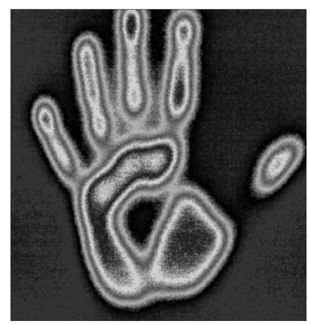


   a) Light-colored or silvery objects:

   b) Dark objects:

4. An object will also . . .

5. a) If the rate of absorption > rate of radiation then . . .



   b) If the rate of absorption = rate of radiation then . . .

   c) If the rate of absorption < rate of radiation then . . .

6. An idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence, is called a . . .

7. An object that is a good absorber of radiation is also a good emitter of radiation. Therefore, the radiation emitter by a "perfect" emitter is known as . . .

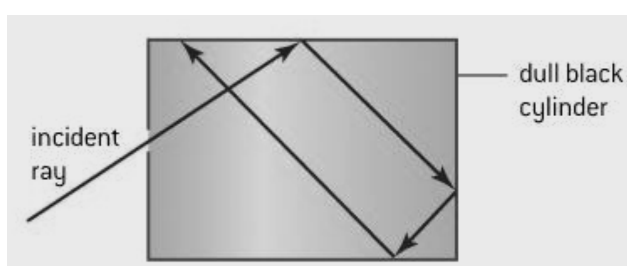
   NOTE: A "black-body" will not appear black if it is hot enough to emit visible light.

   Examples of black-bodies:

   a)

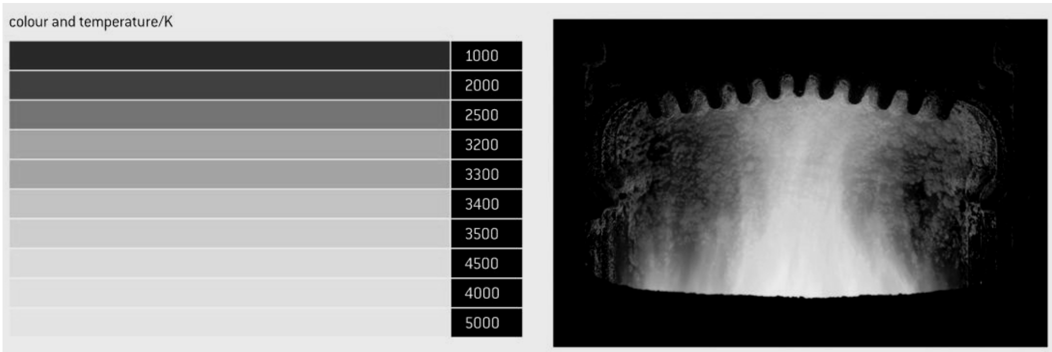
   b)

   c)



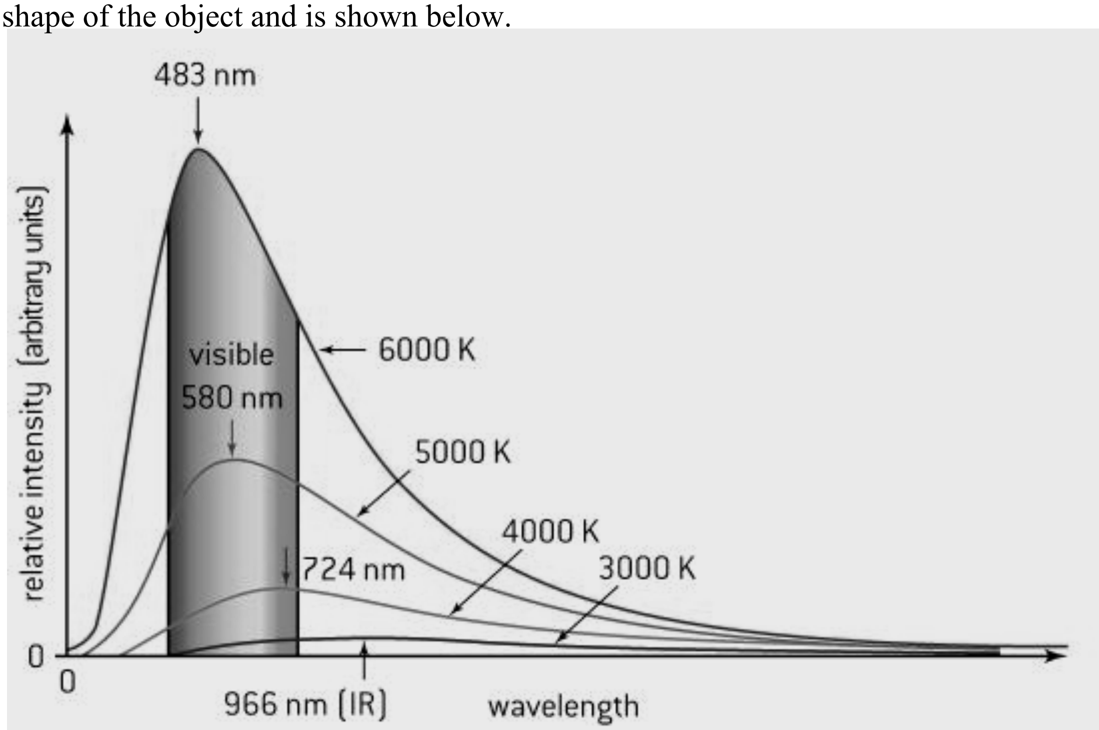
A black-body enclosure.

8. The colors of the radiation emitted by a hot object can tell us about its . . .



Interior of furnace.

Although there is a predominant color to the radiation emitter by a black-body radiator, the entire EM spectrum is emitted in differing amounts (intensities). A graph of the relative intensity of the radiation versus wavelength does not depend on the material or shape of the object and is shown below.



Intensity against wavelength for black bodies at four temperatures.

a) Not all wavelengths of light will be emitted with equal intensity.

b) Emitted wavelength with highest intensity (λ_{max}) is related to . . .

c) Area under curve is proportional to . . .

d) As body heats up, λ_{max} . . . and total power . . .

Wien's Displacement Law:
The wavelength at which the maximum power is emitted by a black-body is inversely proportional to its absolute temperature.

Formula:

9. Determine the frequency of radiation that is emitted by the Sun with the highest intensity. Assume the Sun to be a black-body with a temperature of 5778 K.

	Definition	Formula	Units
Power	energy per unit time		
Intensity	power per unit area		

The Stefan-Boltzmann Law of Radiation:
The total power radiated by a black-body per unit area is proportional to the fourth power of the absolute temperature of the body.

Formula:

where σ=

σ=

Emissivity (e): the ratio of the power emitted by an object to the power emitted by a black-body of the same dimensions at the same temperature

Material	Emissivity
water	0.6–0.7
snow	0.9
ice	0.98
soil	0.4–0.95
coal	0.95

Formula:

10. What is the emissivity of a perfect black-body?

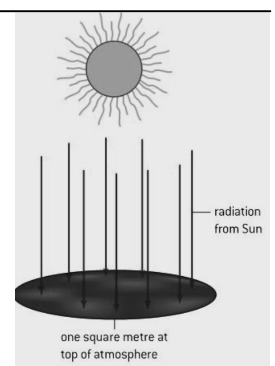
11. The supergiant star Betelgeuse has a surface temperature of about 2900 K and a radius of 3×10^{11} m.

a) Determine how much energy Betelgeuse radiates each second if it is assumed to be a black-body.

b) How will the power radiated by Betelgeuse change if its temperature doubles?

c) Calculate the intensity of the energy radiated by Betelgeuse at its surface.

Solar Radiation



Defining the solar constant.

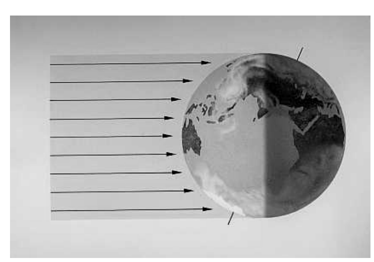
Solar constant

Meaning: The amount of energy from the Sun that arrives at the top of the atmosphere

Definition: The total radiation energy received from the Sun per unit of time per unit of area on a theoretical surface perpendicular to the Sun's rays and at Earth's mean distance from the Sun.

Value of solar constant:

Average value over entire surface of Earth:



Albedo(α): ratio of total solar power scattered (reflected) to total solar power incident

Formula:

Meaning of albedo: the fraction of total incoming solar radiation that is reflected back out into space

Surface	Albedo
Ocean	0.06
Fresh snow	0.85
Sea ice	0.60
Ice	0.90
Urban areas	0.15
Desert soils	0.40
Pine forest	0.15
Deciduous forest	0.25

1. What reflects the radiation?

2. Why does ice have the highest albedo?

3. What is the global mean albedo?

4. The Earth's albedo varies daily and is dependent on:

   i) Season ii) Cloud formations iii) Latitude

5. If the average solar intensity is 340 W/m^2, how much of that is:

   a) reflected from the Earth?

Atmosphere

Ground

   b) transmitted through to the Earth's surface (assuming no absorption by the atmosphere)?

   c) If the Earth is assumed to be a spherical black body with a mean radius of 6.37 x 10^5 meters, calculate its expected surface temperature.

The Greenhouse Effect

Why isn't the Earth's surface temperature 255 K (-18^0 C)?

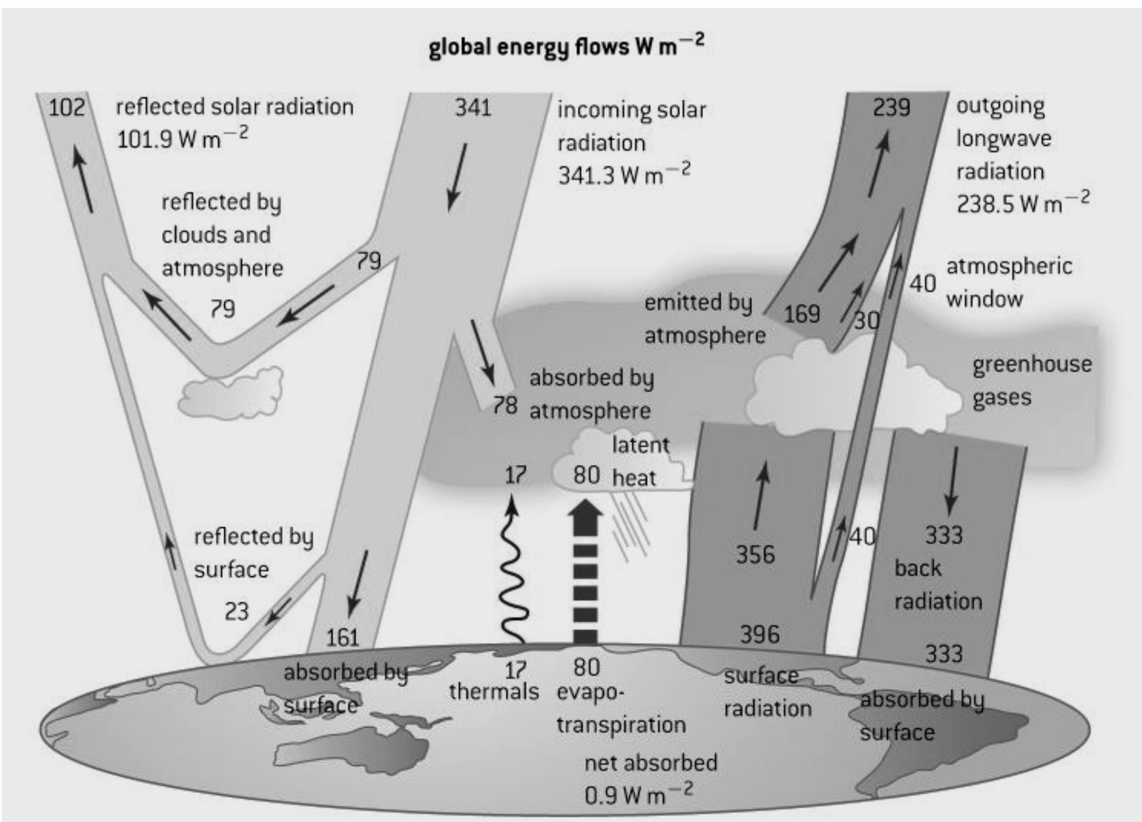
Greenhouse Effect –

a) Short wavelength radiation (ultraviolet, visible, and short-wave infrared) received from the Sun causes the Earth's surface to warm up.

b) Earth will then re-emit longer wavelength radiation (long-wave infrared) which is absorbed by some gases (greenhouse gases) in the atmosphere.

c) This energy is re-radiated in all directions (scattering). Some is sent out into space and some is sent back down to the ground and atmosphere.

d) The "extra" energy re-radiated causes additional warming of the Earth's atmosphere and surface. This additional warming is known as the Greenhouse Effect.

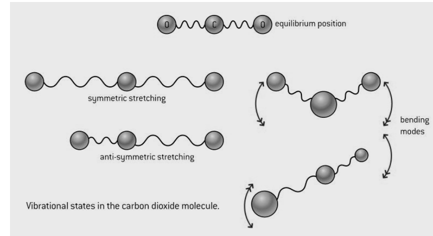


▲ Figure 17 Factors that make up the energy balance of the Earth [after Stephens and others. 2012. *An update on earth's energy balance in light of the latest global observations*. Nature Geoscience.].

Greenhouse Gases: each has natural and man-made origins

1. What is the molecular mechanism by which greenhouse gases absorb infrared radiation?

   Resonance –



Vibrational states in the carbon dioxide molecule.

2. Sketch and annotate a diagram depicting how the greenhouse effect leads to a surface temperature of 288 K.

Additional Practice

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12 An old-fashioned steam train had an output power of 2.3 MW but an efficiency of only 8.4 per cent. If the coal used had a specific energy of 29 MJ kg^{-1}, how much coal had to be burned every minute?

13 a How much fuel (kerosene) does a jet airliner consume every second when travelling at a constant speed of 240 m s^{-1} with a power output of 89 MW? Assume that the fuel has an energy density of 37 MJ m^{-3} and the engines have an efficiency of 39 per cent.
b What is the resistive force acting on the airliner?
c Estimate the amount of fuel needed to travel a distance of 5000 km at this constant height and speed.

14 A 220 MW oil-fired power station has an efficiency of 40 per cent and uses fuel at a rate of 13 kg s^{-1}. What is the specific energy of the fuel?

15 a What is the efficiency of a coal-fired power station that produces an average 560 MW of output power when burning fuel at a rate of 4.8×10^6 kg every day? (Assume that the specific energy of the coal is 30 MJ kg^{-1}.)
b If the discarded thermal energy was removed from the power station by cooling water, which should not increase in temperature by more than 4.0°C, calculate the minimum rate of flow of cooling water that would be needed. The specific heat capacity of water is 4180 J kg^{-1} °C^{-1}.
c Estimate the mass of coal that must be burned every year to supply the needs of a large home that uses an average power of 3 kW.

12) 57 kg 13) a) 6.2 m^3 b) 3.7×10^5 N c) 1.3×10^5 m^3 14) 42 MJ/kg

15) a) 34% b) 6.5×10^4 kg/s c) 9300 kg

32 A wind generator has blades of length 18 m and operates with an efficiency of 21 per cent. What power output would you expect with a 12 m s^{-1} wind? (Density of air = 1.3 kg m^{-3}.)

33 A wind generator has an output of 10 kW when the wind speed is 8 m s^{-1}.
a What wind speed would be needed for an output of 20 kW?
b What power output would you predict for another generator of similar design, but with blades of twice the length, when the wind speed was 16 m s^{-1}?

34 A small farmhouse needs an average power of 4 kW. A wind generator is to be placed on the top of a tower where the effective average wind speed is 7.5 m s^{-1}. Calculate the length of blades needed to generate this power if the system is 24 per cent efficient.

39 Calculate the maximum theoretical power available from a hydroelectric power station in which 2.0 m^3 of water falls a vertical distance of 112 m every second. Assume that the density of water is 1000 kg m^{-3}.

40 What is the total gravitational potential energy available from a lake of area 5.8 km^2 and average depth of 33 m which supplies a hydroelectric power station that is 74 m below the bottom of the lake? Think carefully about what height you should use in the calculation.

41 Water flows from a lake through a certain hydroelectric power station at an average annual rate of 4.3 $m^3 s^{-1}$.
a If the water in the lake comes from the rainfall over an area of 138 km^2, what is the average rainfall (in cm y^{-1}) over that area?
b What assumption did you have to make? Is it reasonable?

42 A family wants to install a small hydroelectric generator to provide their own electrical needs, which they estimate to be an average of 3.0 kW. The generator's efficiency is 85 per cent. If their home is at an altitude of 1420 m and they want to use water falling from a small lake at an altitude of 1479 m, what average mass of water must pass through the generator every second?

52 A photovoltaic cell of area 1.8 cm^2 is placed where it receives radiation at a rate of 700 W m^{-2}.
a What electrical power is produced if its efficiency is 18 per cent?
b If the voltage across it is 0.74 V, calculate the current through the cell.
c How many cells would be needed for a power output of 50 W?
d What would be the total area of the cells?

55 A solar heating panel of area 3.4 m^2 is put in a position such that on one day it received an average intensity of 640 W m^{-2} during 12 hours of daylight.
a What is the total energy incident on the panel during that day?
b The system is designed to transfer this energy to a 0.73 m^3 tank of water, and at the start of the day the temperature of the water in the tank was 2°C. What is the maximum possible temperature of the water at the end of the day? (Assume that the density of water is 1000 kg m^{-3} and that the specific heat capacity of water is 4200 J kg^{-1} °C^{-1}.)
c What assumption did you make?

32) 2.4 x 10^5 W   33) a) 10 m/s b) 320kW   34) 4.4 m

39) 2.2 x 10^6 W 40) 1.7 x 10^{14} J 41) a) 98 cm   42) 6.1 kg

52) a) 0.023 W b) 0.031 A c) 2200 d) 0.39 m^2 55) a) 9.4 x 10^7 J b) 33° C

56. Copy the graph to the right and sketch / label two black-body curves on the graph: One for an object at temp T and one for and object at temp 2T

57. What is the wavelength of the maximum intensity radiation emitted by a black-body that is at a temperature of 4750 K?

A sphere of radius 1.50 m is heated up to a temperature of 450. K.
58. Find the rate at which it should be emitting black-body radiation.
59. If the emissivity of the sphere is 0.500, what is the actual power being radiated by it?
An object is absorbing heat at a rate of 2500. W and radiating it at a rate of 2200. W.
60. What is its emissivity?

The following question refers to this energy model.
63. This model shows an unstable temperature. What evidence is there to justify this statement.