ENERGY CLIMATE PROBLEMS - SOLUTIONS

1. This question is about energy sources.

(a) Fossil fuels are being produced continuously on Earth and yet they are classed as being non-renewable. Outline why fossil fuels are classed as non-renewable.

   (a) (natural process of) production takes thousands/millions of years but fossil fuels are used much faster than being produced

(b) Some energy consultants suggest that the solution to the problem of carbon dioxide pollution is to use nuclear energy for the generation of electrical energy. Identify two disadvantages of the use of nuclear fission when compared to the burning of fossil fuels for the generation of electrical energy.

   (b) storage of radioactive waste; increased cost; risk of radioactive contamination etc.

2. This question is about solar energy.

(a) By reference to energy transformations, distinguish between a solar panel and a solar cell.

   (a) solar panel: solar energy → thermal energy (heat);
   solar cell: solar energy → electrical energy

Some students carry out an investigation on a solar panel. They measure the output temperature of the water for different solar input powers and for different rates of extraction of thermal energy. The results are shown below.

(b) Use the data from the graph to answer the following.

(i) The solar panel is to provide water at 340 K whilst extracting energy at a rate of 300 W when the intensity of the sunlight incident normally on the panel is 800 Wm$^{-2}$. Calculate the effective surface area of the panel that is required.

   (b) (i) input power required = 730 W (± 5 W); 
   Area = 730/800 = 0.91 m$^2$

(ii) Deduce the overall efficiency of the panel for an input power of 500W at an output temperature of 320K.

   (ii) power extracted (graph) = 165 W (± 20 W)
   efficiency = (power out)/(power in) = 165/500 = 33 %

3. This question is about the production of electrical energy.

(a) Outline the principal energy transfers involved in the production of electrical energy from thermal energy in a coal fired power station.

   (a) thermal energy → mechanical energy/KE → electrical energy;
       (in turbines or coil rotated in a magnetic field)

   Heat energy is produced by the combustion of coal in a furnace. Liquid water absorbs the heat energy in a heat exchanger under pressure, and it is turned into steam. Steam under pressure is capable of doing mechanical work to supply the kinetic energy to turn the steam turbines. The turbine is coupled to the generator that produces electrical energy (coil rotated in a magnetic field).
(b) State and explain whether the energy sources used in the following power stations are renewable or non-renewable.
(i) Coal fired
(ii) Nuclear
(b) both non renewable

in both cases a resource is being used and isn’t being replaced.

(c) The core of some nuclear reactors contains a moderator and control rods. Explain the function of these components.

(i) The moderator
(c) (i) to slow down fast moving neutrons so as to increase chances of neutron capture by another uranium nucleus.

(ii) The control rods
(ii) to absorb neutrons so as to control rate of reaction

(d) Discuss one advantage of a nuclear power station as opposed to a coal-fired power station.

4. This question is about wind energy.

It is required to design wind turbines for a wind farm for which the following information is available.
Total required annual electrical energy output from the wind farm = 120 TJ
Maximum number of turbines for which there is space on the farm = 20
Average annual wind speed at the site = 9.0 ms⁻¹ (Density of air = 1.2 kg m⁻³)

(a) Deduce that the average power output required from one turbine is 0.19 MW.

\[ P = \frac{1}{2} \rho A v^3 \]
\[ A = \frac{2P}{\rho v^2} = \frac{2 \times 1.9 \times 10^6}{1.2 \times 9.0^2} = 4.3 \times 10^2 m^2 \]
\[ r = (A/\pi)^{1/2} = 12 m \]

(b) Estimate the blade radius of the wind turbine that will give a power output of 0.19 MW.

Therefore for one turbine: \( 3.8 \times 10^6 / 20 = 0.19 MW \)

(c) State one reason why your answer to (b) is only an estimate.

(c) the wind speed varies over the year / not all the wind energy will be transferred into mechanical power / energy loss due to friction in the turbine / energy loss in converting to electrical energy / density of air varies with temperature;

(d) Discuss briefly one disadvantage of generating power from wind energy.

(d) take up so much room - not possible to produce enough energy to meet a country’s requirements – noisy and this could have an effect on local fauna;

5. This question is about the production of nuclear energy and its transfer to electrical energy.

(a) When a neutron “collides” with a nucleus of uranium-235 (U) the following reaction can occur

\[ ^{235}_{92}U + _{0}^{1}n \rightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2_0^1n \]

(i) State the name given to this type of nuclear reaction.

\( a) \ (i) \ fission \)

(ii) Energy is liberated in this reaction. In what form does this energy appear?

\( ii \ kinetic \ energy \)
(b) Describe how the neutrons produced in this reaction may initiate a chain reaction. (1)

(b) the two neutrons can cause fission in two more uranium nuclei producing four neutrons so producing eight etc.

The purpose of a nuclear power station is to produce electrical energy from nuclear energy. The diagram below is a schematic representation of the principle components of a nuclear reactor ‘pile’ used in a certain type of nuclear power station.

The function of the moderator is to slow down neutrons produced in a reaction such as that described in part (a) above. (c) (i) Explain why it is necessary to slow down the neutrons. (3)

(c) (i) the fuel rods contain a lot more U-238 than U-235; neutron capture is more likely in U-238 than U-235 with high energy neutrons; but if the neutrons are slowed they are more likely to produce fission in U-235 than neutron capture in U-238; The argument is a little tricky. One needs to know about there being two isotopes present in the fuel and something about the dependence of the fission and capture in the two isotopes on neutron energy.

(ii) Explain the function of the control rods. (2)

(ii) control the rate at which the reactions take place by absorbing neutrons.

(d) Describe briefly how the energy produced by the nuclear reactions is extracted from the reactor pile and then transferred to electrical energy. (4)

(d) four main points,
energy lost by the slowing of the neutrons and fission elements heats the pile; this heat extracted by the molten sodium / pressurised water / other suitable substance; which is pumped to a heat exchanger; water is pumped through the heat exchanger and turned to steam; the steam drives a turbine; which is used to rotate coils (or magnets) placed in a magnetic field (or close to coils) which produces electrical energy;

6. This question is about nuclear power and thermodynamics.

(a) A fission reaction taking place in the core of a nuclear power reactor is

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

(i) State one form in which energy is released in this reaction. (1)

(a) (i) kinetic energy of the fission products / neutrons / photons (no thermal energy or heat - that’s the consequence)

(ii) Explain why, for fission reactions to be maintained, the mass of the uranium fuel must be above a certain minimum amount. (2)

(ii) if mass of uranium is too small too many neutrons escape; without causing fission in uranium / reactions cannot be sustained;
(iii) The neutrons produced in the fission reaction are fast moving. In order for a neutron to fission U-235 the neutron must be slow moving. Name the part of the nuclear reactor in which neutrons are slowed down.  

(iii) the moderator (and the fuel rods)

(iv) In a particular reactor approximately $8.0 \times 10^{19}$ fissions per second take place. Deduce the mass of U-235 that undergoes fission per year.

(iv) mass of uranium atom = $235 \times 1.661 \times 10^{-27} \text{kg} = 3.90 \times 10^{-25} \text{kg}$

or $\frac{0.325}{6.02 \times 10^{23}} \text{kg}$

mass of uranium per second = $3.90 \times 10^{-25} \times 8 \times 10^{19} = 3.12 \times 10^{-5} \text{kg s}^{-1}$

mass of uranium per year = $3.12 \times 10^{-5} \times 365 \times 24 \times 60 \times 60 = 984 = 9.8 \times 10^{2} \text{kg yr}^{-1}$

(b) The thermal power from the reactor is 2400 MW and this is used to drive (operate) a heat engine. The mechanical power output of the heat engine is used to drive a generator. The generator is 75% efficient and produces 600 MW of electrical power. This is represented by the energy flow diagram below.

(i) Calculate the power input to the generator.  

(b) (i) $P_{\text{output}} = 0.75 P_{\text{input}} \quad 600 = 0.75 P_{\text{input}} \quad P_{\text{input}} = 800 \text{ MW};$

(ii) Calculate the power lost from the generator.  

(ii) 200 MW

(iii) Calculate the power lost by the heat engine.  

(iii) 1600 MW

(iv) State the name of the law of physics which prohibits all of the 2400 MW of input thermal power from being converted into mechanical power.  

(iv) the second law of thermodynamics

(v) Deduce that that the efficiency of the heat engine is 33%.  

(v) $\frac{800}{2400} = 0.33 = 33\%$

7. This question is about wind power.

(a) A wind turbine produces 15 kW of electric power at a wind speed $v$.  

(i) Assuming a constant efficiency for the wind turbine, determine the power output of the turbine for a wind speed of $2v$.  

(a) (i) $P \propto v^3 \quad P = 15 \times 2^3 = 120 \text{ kW}$
(ii) Suggest two reasons why all the kinetic energy of the incident wind cannot be converted into mechanical energy in the turbine.

(ii) The wind speed will not be reduced to zero after impact with blades; power will be less because of frictional losses / turbulence;

(b) State and explain one advantage of using wind power to generate electrical energy as compared to using fossil fuels. (2)

(b) Wind power is renewable; while fossil fuels are finite;

8. A wind generator converts wind energy into electric energy. The source of this wind energy can be traced back to solar energy arriving at the Earth’s surface.

(a) Outline the energy transformations involved as solar energy converts into wind energy. (2)

(a) Solar energy (electromagnetic waves) → thermal energy → kinetic energy of wind

(b) List one advantage and one disadvantage of the use of wind generators. (2)

(b)

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No fuel costs</td>
<td>Need a windy location</td>
</tr>
<tr>
<td>Renewable</td>
<td>Power output is low</td>
</tr>
<tr>
<td>Non-polluting</td>
<td>Environmentally noisy</td>
</tr>
<tr>
<td></td>
<td>High maintenance costs due to metal stress and strain</td>
</tr>
</tbody>
</table>

The expression for the maximum theoretical power, \( P \), available from a wind generator is \( P = \frac{1}{2} A \rho v^3 \) where \( A \) is the area swept out by the blades, \( \rho \) is the density of air and \( v \) is the wind speed.

(c) Calculate the maximum theoretical power, \( P \), for a wind generator whose blades are 30 m long when a 20 m/s wind blows. The density of air is 1.3 kg/m³. (2)

(c) \( \begin{align*} P &= \frac{1}{2} A \rho v^3 \\ &= \frac{1}{2} (\pi \times 30^2) \times 1.3 \times (20)^3 \\ &= 15 \text{ MW} \end{align*} \)

(d) In practice, under these conditions, the generator only provides 3 MW of electrical power.

(I) Calculate the efficiency of this generator. (2)

\( (d) \ (i) \) Efficiency = power output / power input = 3 MW / 15 MW = 0.2 = 20 %

(ii) Give two reasons explaining why the actual power output is less than the maximum theoretical power output. (2)

(ii) Not all the wind energy will be transferred into mechanical power / energy loss due to friction in the turbine / energy loss in converting to electrical energy / density of air varies with temperature

9. This question is about energy sources.

(a) Give one example of a renewable energy source and one example of a non-renewable energy source and explain why they are classified as such. (4)

give one + one

(b) A wind farm produces 35000 MWh of energy in a year. If there are ten wind turbines on the farm show that the average power output of one turbine is about 400 kW. (3)

\( \text{(b) Energy} = \text{power} \times \text{time} \quad \text{power} = 35000 \text{ MWh} / 365 \times 24 \text{h} = 4.0 \text{ MW} \)

\( \text{Power of one} = 4.0 \times 10^6 \text{ W} / 10 = 4.0 \times 10^5 \text{ W} = 400 \text{ kW} \)

(c) State two disadvantages of using wind power to generate electrical power. (c)

\( \text{(c) Need a windy location} \)
\( \text{Power output is low} \)
\( \text{Environmentally noisy} \)
\( \text{High maintenance costs due to metal stress and strain} \)
10. This question is about energy transformations.

Wind power can be used to generate electrical energy. Construct an energy flow diagram which shows the energy transformations, starting with solar energy and ending with electrical energy, generated by windmills. Your diagram should indicate where energy is degraded.

11. Copy and complete the following table to show the energy conversions for various devices. (There could be more than one type of energy produced).

<table>
<thead>
<tr>
<th>Device</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cigarette lighter</td>
<td>Chemical to thermal and light</td>
<td></td>
</tr>
<tr>
<td>Human body</td>
<td>Chemical to thermal and kinetic</td>
<td></td>
</tr>
<tr>
<td>Microphone</td>
<td>Sound to electrical</td>
<td></td>
</tr>
<tr>
<td>Car engine</td>
<td>Chemical to thermal and kinetic and sound</td>
<td></td>
</tr>
<tr>
<td>Light bulb</td>
<td>Electrical to light and thermal</td>
<td></td>
</tr>
<tr>
<td>Light emitting diode</td>
<td>Electrical to light</td>
<td></td>
</tr>
<tr>
<td>Refrigerator</td>
<td>Electrical to thermal</td>
<td></td>
</tr>
<tr>
<td>Stereo speaker</td>
<td>Electrical to sound</td>
<td></td>
</tr>
<tr>
<td>Thermocouple</td>
<td>Thermal to electrical</td>
<td></td>
</tr>
<tr>
<td>Atomic bomb</td>
<td>Nuclear to thermal, sound and light</td>
<td></td>
</tr>
</tbody>
</table>

12. A sample of lignite has a moisture content of 65%.

(a) Determine how much water is in a 10 tonne sample of this coal before crushing and drying?

(a) There is 65% moisture content. Therefore, the amount of water will be 0.65 \times 10 000 kg = 6 500 kg

(b) Explain how the moisture content will reduce the amount of heat that can be obtained from combustion of the coal.

(b) The more water present, the less coal there is to burn and some of the heat released has to be used to heat and evaporate the water.

13. A sample of anthracite has a moisture content of 5% and when dried it has an energy density of 35 kJ g\(^{-1}\). Assuming that during coal combustion the temperature of the water in the coal is raised from 20\(^\circ\)C to 100\(^\circ\)C and then vaporised at 100\(^\circ\)C, estimate the energy density of the coal as it is mined.

Energy required to convert the water to steam = mc\(\Delta T\) + mL\(v\)

Since there is 5% moisture content, there is 5 g of water per 100g of coal. For 5 grams,

\[ Q = 5g \times 4.18 \, \text{J} \, \text{g}^{-1} \, \text{K}^{-1} \times (100 \, ^\circ\text{C} - 20 \, ^\circ\text{C}) + 5g \times (22.5 \times 10^2 \, \text{J} \, \text{g}^{-1}) = 12 \, 922 \, \text{J} = 13 \, \text{kJ} \]

The energy density in the other 95 grams of anthracite is 28kJ g\(^{-1}\) \times 95 = 2 660 kJ

The total usable energy in 100 grams = 2 660 − 13 kJ = 2 647 kJ

For one gram this would be 2.65 kJ

The energy density as it is mined will be 2.65 kJ per gram less than when the coal is dried.

= 35 kJ g\(^{-1}\) − 2.65 kJ g\(^{-1}\)

The energy density of the coal as it is mined is 32.4 kJ g\(^{-1}\). 

14. A coal-fired power station burns coal with 50% moisture content. The composition of the dried sample is found to contain on analysis 72% carbon, 5% hydrogen and 23% oxygen. If 500 tonnes is burnt hourly:

(a) Assuming the hydrogen and oxygen is converted to steam, the total amount of steam = 50% + 28% of the remaining 50% = 50% + 14% = 64%

64% of 500 tonnes = 320 tonnes.

(b) $320 \times 24 \times 7 = 5.4 \times 10^4$ tonnes

(c) 1 tonne = 1000 kg

$1 dm^3 = 1 litre = 1 kg$

$5.4 \times 10^4$ tonnes $\times 1000 = 5.4 \times 10^7 dm^3$

15. A 250 MW coal-fired power station burns coal with an energy density of 35 MJ kg$^{-1}$. Water enters the cooling tower at a temperature of 293 K and leaves at a temperature of 350 K and the water flows through the cooling tower at the rate of 4200 kg s$^{-1}$.

(a) Calculate the energy removed by the water each second.

(a) The power station produces 250 MW of power per second

$Q = mc\Delta T = 4200 \times 4180 \times 10^9 \times (350 - 293) \times 10^9 J$

$= 1 \times 10^9 \times 1000 = 1 \times 10^9$ J per second = 1000 MW.

(b) Calculate the energy produced by the combustion of coal each second.

(b) The answer is 1250 MW. 1000 MW is degraded in the cooling tower and there is 250 MW output as electrical energy. Therefore, the energy produced by combustion of coal = 1000 + 250 = 1250 MW.

(c) Calculate the overall efficiency of the power station.

(c) Efficiency =

$= \frac{\text{useful energy output}}{\text{total energy Input}} \times 100%$

$= \frac{250}{1250} \times 100% = 20%$

(d) Calculate the mass of coal burnt each second.

(d) $1250 \times 10^6 \div 35 \times 10^6 = 35.7$ kg

16. Why are energy density values of fuels usually expressed in J g$^{-1}$ rather than kJ mol$^{-1}$?

It is determined in joules per gram J g$^{-1}$ or kilojoules per gram kJ g$^{-1}$ as bomb calorimetry is used to determine the value and this technique requires only small masses of a sample. A mole can be a large mass.

17. A schematic diagram of a typical coal-fired power station is shown.

Suggest a reason why coal is ground to a fine powder before combustion.

To increase the surface area of the coal to allow for a greater rate of combustion.
18. A sample of lignite has a moisture content of 65% and when dried it has an energy density of 28 kJ⁻¹. Assuming that during coal combustion the temperature of the water in the coal is raised from 20 °C to 100 °C and then vaporised at 100 °C, estimate the energy density of the coal as it is mined.

Energy required to convert the water to steam = \( mc\Delta T + mL_v \)

Since there is 65% moisture content, there is 45 g of water per 100 g of coal.

The heat energy absorbed to turn 45 grams of water into steam would be:

\[
Q = 45g \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (100^\circ \text{C} - 20^\circ \text{C}) + 45g \times (22.5 \times 10^2 \text{ J g}^{-1})
\]

\[
= 116298 \text{ J} = 116.3 \text{ kJ}
\]

The energy density in the other 65 g of lignite is 28 kJ g⁻¹ x 65 = 1820 kJ.

The total usable energy in 100 grams = 1820 – 116.3 kJ

For one gram this would be 1.16 kJ g⁻¹.

The energy density as it is mined will be 1.16 kJ per gram less than when the coal is dried = 28 kJ g⁻¹ – 1.2 kJ g⁻¹.

The energy density of the coal as it is mined is 26.8 kJ g⁻¹.

19. A coal-fired power station burns coal with 30% moisture content. The composition of the dried sample is found to contain on analysis 70% carbon, 5% hydrogen and 25% oxygen. If 1000 tonnes is burnt hourly:

(a) Estimate the mass of water vapour emitted from the cooling towers each hour?

Assuming the hydrogen and oxygen is converted to steam, the total amount of steam formed is:

\[
= 30\% + 30\% \text{ of the remaining } 50\% = 45\%
\]

45% of 1000 tonnes = 450 tonnes.

(b) Estimate the mass of water vapour produced in a week?

\[
450 \times 24 \times 7 = 7.6 \times 10^4 \text{ tonnes}
\]

(c) Estimate the volume of condensed water vapour produced in a week?

\[
1 \text{ tonne} = 1000 \text{ kg} \quad 1 \text{ dm}^3 = 1 \text{ kg}
\]

\[
7.6 \times 10^4 \text{ tonnes} \times 1000 = 7.6 \times 10^7 \text{ dm}^3
\]

20. It has been suggested that crude oil should be used for other purposes rather than as a transportation fuel. Deduce the reasoning behind this statement.

Crude oil is used in the petrochemical industry to produce many products such as plastics, polymers, pharmaceuticals, synthetic textiles and fabrics. Other fuels such as LPG and LNG have a higher energy density than petrol and there are more supplies of gases than crude oil. The petrol engine is only 25% efficient and a greater efficiency can be obtained from cars that run on liquid petroleum gas.

LPG is cleaner than petrol as it burns more efficiently and it contains less pollutants. In the future, the petrochemical industries will need feedstock to continue to produce products for consumers.

21. Assume that a sample of coal has an empirical formula \( \text{C}_5 \text{H}_4 \) and that a coal-fired power station burns a 1000 tonne of coal per hour.

(a) Write an equation for the complete combustion of the coal.

\[
2 \text{C}_5 \text{H}_4 + 13 \text{O}_2 \rightarrow 8 \text{CO}_2 + 10 \text{H}_2\text{O}
\]

(b) Calculate the mass of oxygen required for his combustion each hour.

One mole of coal (64 grams per mole) requires 6 ½ moles of oxygen (32 grams per mole). The mass in grams in 1000 tonne of coal

\[
= 1000 \text{ tonne} \times 1000 \text{ kg} \times 1000 \text{g} = 10^9 \text{ g}.
\]

The number of mole of coal = \( 10^9 \text{ g} / 64 \text{ g per mol} = 1.56 \times 10^7 \text{ mol}. \)

The number of mol of oxygen = \( 1.56 \times 10^7 \text{ mol} \times 6 \frac{1}{2} = 1.02 \times 10^8 \text{ mol}. \)
Therefore, the mass of oxygen required = 32 \times 1.02 \times 10^7 \text{g} = 3.25 \times 10^4 \text{kg} = 32.5 \text{ tonnes of oxygen.}

(c) If 25 dm$^3$ of oxygen is required per mole, calculate the volume of oxygen that is required each hour for this combustion.

\[
\text{(c) Volume of oxygen} = 25 \text{dm}^3 \times 1.02 \times 10^9 \text{mol} = 2.55 \times 10^{10} \text{dm}^3.
\]

(d) Air contains approximately 20% oxygen. What volume of air is required hourly.

\[
\text{(d) Volume of air} = 4 \times 2.55 \times 10^{10} \text{dm}^3 = 1.02 \times 10^{11} \text{dm}^3.
\]

22. A coal-fired power station has a power output of 500 MW and operates at an efficiency of 35%. The energy density of the coal being consumed during combustion is 31.5 MJ kg$^{-1}$.

(a) Determine the rate at which heat is being produced by the burning coal.

\[
\text{(a) Since 35% efficient heat must be supplied at 500 MW / 0.35 = 1429 MW}
\]

(b) Determine the rate at which coal is being burned.

\[
\text{(b) 1 kg consumed for 31.5 x 10^6 J s}^{-1}. \text{ So for 1429 x 10^6 J s}^{-1} \text{ the kg s}^{-1} \text{ is} \frac{1429}{31.5} = 45.4 \text{ kgs}^{-1}.
\]

(c) The heat is discarded into the cooling towers of the power plant and is then stored in containment reservoirs. Determine the water flow rate needed to maintain the water temperature in the towers at 10°C.

\[
\text{(c) The amount of heat entering the cooling towers} = 1429 – 500 = 929 \text{MW.}
\]

\[
Q = mc\Delta T. \text{ So } Q / t = mc\Delta T / t.
\]

Therefore, \[\frac{m}{t} = \frac{Q}{c\Delta T} \quad m / t = 929 \times 10^6 / 4180 \times 10 = 2.2 \times 10^4 \text{ kgs}^{-1}.
\]

23. Suppose that the average power consumption for a household is 500 W per day. Estimate the amount of uranium-235 that would have to undergo fission to supply the household with electrical energy for a year. Assume that for each fission, 200 MeV is released.

\[
200 \text{MeV} = 200 \times 10^6 \text{eV} \times 1.6 \times 10^{-19} \text{C} = 3.2 \times 10^{11} \text{J}.
\]

\[
500 \text{W} = 500 \text{Js}^{-1}.
\]

The total number of seconds in a year
\[
= 60 \times 60 \times 24 \times 365.25 = 3.16 \times 10^7 \text{s}
\]

Therefore, the total electrical energy per year
\[
= 3.16 \times 10^7 \text{s} \times 500 \text{Js}^{-1} = 1.58 \times 10^{10} \text{Jyr}^{-1}.
\]

1 fission produces 3.2 \times 10^{11} \text{J}. So for 1.58 \times 10^{10} \text{J} there would be
\[
1.58 \times 10^{10} \text{J} / 3.2 \times 10^{11} \text{J} = 4.9375 \times 10^{20} \text{ fissions}.
\]

\[
1u = 1.661 \times 10^{-27} \text{kg}
\]

\[
\text{Mass of uranium-235} = 235 \times 1.661 \times 10^{-27} \text{kg} = 3.9035 \times 10^{-25} \text{kg per fission}
\]

\[
\text{Mass of uranium-235 needed} = 3.9035 \times 10^{-25} \text{kg} \times 4.9375 \times 10^{20} \text{fissions}
\]

\[
= 1.93 \times 10^{-4} \text{kg or 0.193 g}
\]

24. A fission reaction taking place in a nuclear power reactor is

\[
\text{ }^9_0n + \text{ }^{235}_{92}U \rightarrow \text{ }^{144}_{56}\text{Ba} + \text{ }^{90}_{36}\text{Kr} + 3 \text{ }_0^n\text{n}.
\]
Estimate the initial amount of uranium-235 needed to operate a 600 MW reactor for one year assuming 40% efficiency and that for each fission, 200 MeV is released.

\[ \text{200 MeV} = 200 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ C} = 9.6 \times 10^{-11} \text{ J}. \]

\[ \text{600 MW} = 600 \times 10^6 \text{ Js}^{-1}. \]

The total number of seconds in a year = \(60 \times 60 \times 24 \times 365.25 = 3.16 \times 10^7 \text{ s}\)

Per year the total electrical energy = \(3.16 \times 10^7 \text{ s} \times 600 \times 10^6 \text{ Js}^{-1} = 1.896 \times 10^{16} \text{ Jyr}^{-1}. \)

Since 40% efficient, the total energy needed = \(1.896 \times 10^{16} \text{ Jyr}^{-1} / 0.4 = 4.74 \times 10^{16} \text{ Jyr}^{-1}. \)

1 fission produces \(3.2 \times 10^{-11} \text{ J}. \) So for \(4.74 \times 10^{16} \text{ J} \) there would be \(4.74 \times 10^{16} \text{ J} / 3.2 \times 10^{-11} \text{ J} = 1.48125 \times 10^{27} \text{ fissions}. \)

Mass of uranium-235 = \(235 \times 1.661 \times 10^{-27} \text{ kg} = 3.90335 \times 10^{-25} \text{ kg per fission}\)

Mass of uranium-235 needed = \(3.90335 \times 10^{-25} \text{ kg} \times 1.48125 \times 10^{27} \text{ fissions} = 578.2 \text{ kg}\)

25. Why is a \(^{238} _{92} \text{U}\) nucleus more likely to undergo alpha decay than fission as a means of attaining stability?

The longer half-life of the fission process makes alpha decay a more probable form of decay.

26. (a) Explain how fission reactions, once started, are considered to be self-sustaining.

a) Once a reaction is induced by neutron bombardment, the reaction produces additional neutrons to continue the reaction.

(b) How is the chain reaction in nuclear reactors controlled?

b) Moderators slow the majority of neutrons so that the chain reaction proceeds at a reasonable and safe rate.

27. The thermal power from the reactor is 2400 MW and this is used to operate the steam generator and turbine. The mechanical power output of the generator and turbine is used to drive a generator.

The generator is 60% efficient and produces 600 MW of electrical power. This is represented by the energy flow diagram below.

(i) Calculate the power input to the generator.

(i) \(1000 \text{ MW}\)

(ii) Calculate the power lost from the generator.

(ii) \(400 \text{ MW}\)

(iii) Calculate the power lost by the heat engine

(iii) \(1000 \text{ MW}\)
28. (a) What are the strongest arguments in favour of pursuing nuclear fission as a source of energy?
   
a. Arguments for include cheap, readily available fuel, and longevity of fuel supplies, as well as the possibility of recycling fission products for fuel.

(b) What are the strongest arguments against using nuclear fission as source of energy?

b. Arguments against are the possibility of a catastrophic accident, and the risk to the environment and future generations of long term waste disposal.

29. Determine the number of fissions that will occur per second in a 500 MW nuclear reactor. Assume that 200 MeV is released per fission.

   \[
   200 \text{ MeV} = 200 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ C} = 3.2 \times 10^{-19} \text{ J}.
   
   500 \text{ MW} = 500 \times 10^6 \text{ Js}^{-1}.
   
   Therefore, the number of fissions = \frac{500 \times 10^6 \text{ Js}^{-1}}{3.2 \times 10^{-19} \text{ J}} = 1.56 \times 10^{27} \text{ fissions}.
   
30. State three essential differences between chemical bond breaking and nuclear fission.

Chemical bond breaking is endothermic while nuclear fission may be exothermic or endothermic. Fission involves the breakdown of the nucleus while chemical bond breaking involves the rearrangement of electrons. No new elements are formed in chemical bond breaking but they are in nuclear fission. Mass is lost in nuclear fission and retained in chemical bond breaking.

31. Estimate the initial amount of uranium-235 needed to operate a 500 MW reactor for one year assuming 35% efficiency and that for each fission, 200 MeV is released.

   \[
   200 \text{ MeV} = 200 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ C} = 9.6 \times 10^{-11} \text{ J}.
   
   500 \text{ MW} = 500 \times 10^6 \text{ Js}^{-1}.
   
   Total number of seconds in a year = 60 \times 60 \times 24 \times 365.25 = 3.16 \times 10^7 \text{ s}.
   
   Per year the total electrical energy = 3.16 \times 10^7 \text{ s} \times 500 \times 10^6 \text{ Js}^{-1} = 1.58 \times 10^{16} \text{ Jyr}^{-1}.
   
   Since 35% efficient, the total energy needed = \frac{1.896 \times 10^{16} \text{ Jyr}^{-1}}{0.35} = 4.51 \times 10^{16} \text{ Jyr}^{-1}.
   
   1 fission produces 3.2 \times 10^{-11} \text{ J}. So for 4.51 \times 10^{16} \text{ J} there would be
   
   4.51 \times 10^{16} \text{ J} / 3.2 \times 10^{-11} \text{ J} = 1.41 \times 10^{27} \text{ fissions}.
   
   Mass of U-235 = 235 \times 1.661 \times 10^{-27} \text{ kg} = 3.90335 \times 10^{-25} \text{ kg per fission}
   
   Mass of U-235 needed = 3.90335 \times 10^{-25} \text{ kg} \times 1.41 \times 10^{27} \text{ fissions} = 550.2 \text{ kg}
   
32. A solar panel with dimensions 2 m by 4 m is placed at an angle of 30° to the incoming solar radiation. On a clear day, 1000 Wm⁻² reaches the Earth’s surface. Determine how much energy can an ideal solar panel generate in a day.

Area of the solar panel = 8 m².
Area in radiation terms = 8 \cos 30° = 6.93 m²
1000 Wm⁻² = 1000 J s⁻¹ m⁻²
Energy produced / day = (1000 J s⁻¹ m⁻²)(6.93 m²)(24 x 60 x 60)s = 5.98 \times 10^{8} \text{ J}

33. An active solar heater of volume 1.4 m³ is to provide the energy to heat water from 20 °C to 50 °C. The average power received from the Sun is 0.90 kWm⁻².

(a) Deduce that 1.8 \times 10^6 \text{ J} of energy is required to heat the volume of water in the tank from 20 °C to 50 °C.

(a) mass of water = 1.4 \times 10^3 \text{ kg}; \text{ energy required } = 1.4 \times 10^3 \text{ kg} \times 4.18 \times 10^3 \text{ Jkg}^{-1} \degree \text{ C} \times 30 \degree \text{ C} = 1.8 \times 10^6 \text{ J}.

(b) Estimate the minimum area of the solar panel needed to provide 1.8 \times 10^6 \text{ J} of energy in 2.0 hours.

(b) energy provided in 2 hours = 7200 \times 900 \times A,
therefore A = (1.8 \times 10^6 \text{ J}) / (7200 s \times 900 \text{ Js}^{-1}) = 27.8 \text{ m}².
34. A barrage is placed across the mouth of a river as shown in the diagram of a tidal power station. If the barrage height is 15 m and water flows through 5 turbines at a rate of $1.0 \times 10^2$ kg per second in each turbine, calculate the power that could be produced if the power plant is 70% efficient. Assume the density of seawater is 1030 kgm$^{-3}$.

Because the water level will change the average height of water = $h/2$.

Power = $P = \rho \times g \times 0.5h \times \text{volume per second}$

= 1030 kgm$^{-3} \times 100$ kg s$^{-1} \times 9.8$ m s$^{-2} \times 7.5$ m $\times 5$ turbines

= $37.85 \times 10^6$ J s$^{-1}$

If 70% efficient then the power produced = $0.7 \times 37.85 \times 10^6$ J s$^{-1}$

Total power = 26.5 MW.

35. If water from a pumped storage dam fell through a pipe 150 m at a rate of 500 kg per second, calculate the power that could be produced if the power plant is 60% efficient. Assume the density of water is 1000 kgm$^{-3}$.

Solution

Power = $\rho g \Delta h \times \text{volume per second}$

= $1000$ kgm$^{-3} \times 500$ kg s$^{-1} \times 9.8$ m s$^{-2} \times 150$ m $= 735 \times 10^6$ J s$^{-1}$

If 60% efficient then the power produced = $0.6 \times 441 \times 10^6$ J s$^{-1}$

Total power = 441 MW

36. A wind turbine has blades 20 m long ($r = 10$ m ???) and the speed of the wind is 25 ms$^{-1}$ on a day when the air density is 1.3 kgm$^{-3}$.

Calculate the power that could be produced if the turbine is 30% efficient.

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

$A = \pi r^2$

$P = \frac{1}{2} \pi r^2 \rho v^3$

$P = 0.3 \times 0.5 \times \pi \times 10^2$ m$^2 \times 1.3$ kgm$^{-3} \times 25^3$ m$^3$s$^{-3}$

$= 9.57 \times 10^6$ W

= 0.96 MW

37. A wind generator is being used to power a solar heater pump. If the power of the solar heater pump is 0.5 kW, the average local wind speed is 8.0 ms$^{-1}$ and the average density of air is 1.1 kgm$^{-3}$, deduce whether it would be possible to power the pump using the wind generator.

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

$A = \pi r^2$

$P = 500$ Js$^{-1} = \frac{1}{2} \pi r^2 \rho v^3$

$r = \sqrt[3]{\frac{2P}{\pi \rho v^3}} = \sqrt[3]{\frac{2 \times 500\text{Js}^{-1}}{\pi \times (1.1 \text{kgm}^{-3}) (8.0 \text{ms}^{-1})^3}}$

$r = 0.75$ m

This is a small diameter so it could be feasible provided the wind speed was always present.
38. If a wave is 3 m high and has a wavelength of 100 m and a frequency of 0.1 s\(^{-1}\), estimate the power for each metre of the wave.

\[
\text{Power per unit length} = \frac{1}{2} \rho g A^2 v \quad A = 1.5 \text{ m} \quad v = \lambda f
\]

\[
\text{Power per unit length} = \frac{1}{2} \rho g A^2 \lambda f
\]

\[
\text{Power} = 0.5 \times 1020 \text{ kg/m}^3 \times 10 \text{ m/s}^2 \times (1.5)^2 \text{ m}^2 \times 100 \text{ m} \times 0.1 \text{ s}^{-1}
\]

\[
= 1.14 \times 10^6 \text{ kg m}^2 \text{s}^{-3}
\]

\[
= 114 \text{ kW per metre.}
\]

39. If a wave is 3 m high and has a wavelength of 100 m and a period of 8 s, estimate the power over each metre of wavefront and calculate the wave speed.

\[
\text{speed} = \frac{\lambda}{T} = 100 \text{ m} / 8 \text{ s} = 12.5 \text{ ms}^{-1}
\]

\[
\text{Power} = \frac{1}{2} \rho g A^2 v
\]

\[
= 0.5 \times 1020 \text{ kg/m}^3 \times 10 \text{ m/s}^2 \times (1.5)^2 \text{ m}^2 \times 12.5 \text{ ms}^{-1}
\]

\[
= 143 \times 10^3 \text{ kg m}^2 \text{s}^{-3}
\]

\[
= 143 \text{ kW per metre.}
\]

40. In terms of energy transformations, distinguish between a solar panel and a solar cell.

- Solar panel: solar energy → thermal energy (heat).
- Solar cell: solar energy → electrical energy.

41. A wind turbine farm is being designed for a town with a total required energy of 150 TJ per year. There is available space for 25 turbines and the average annual wind speed is 15 ms\(^{-1}\).

(a) Deduce that the average required output from one turbine is 0.19 MW.

(b) Estimate the blade radius of the wind turbine that will give a power output of 0.19 MW. (Density of air = 1.3 kg m\(^{-3}\))

ANS:

(a) \[
\text{power} = \frac{\text{energy}}{\text{time}}
\]

\[
= 150 \times 10^{12} \text{ J} / 60 \times 60 \times 24 \times 365 = 4.75 \times 10^6 \text{ MW therefore,
for one turbine} = \frac{4.75 \times 10^6}{25} = 0.19 \text{ MW}
\]

(b) \[
\text{Power} = \frac{1}{2} A \rho v^3
\]

\[
= \frac{2P}{\pi \rho v^3} = \frac{2 \times 0.19 \times 10^8 \text{Js}^{-1}}{\pi \times (1.3) \text{kgm}^{-3} \times (15 \text{ms}^{-1})^3} = 5.25 \text{ m}
\]

42. An active solar heater of volume 2.4 m\(^3\) is to provide the energy to heat water from 20 °C to 60 °C. The average power received from the Sun is 1000 Wm\(^{-2}\).

(a) Deduce that 4.0 \times 10^8 J of energy is required to heat the volume of water in the tank from 20 °C to 60 °C.

(a) \[
\text{mass of water} = 2.4 \times 10^3 \text{ kg};
\]

\[
\text{energy required} = mc\Delta T
\]

\[
Q = 2.4 \times 10^3 \text{ kg} \times 4.18 \times 10^3 \text{ Jkg}^{-1} \text{C} \times (60 - 20) \text{ C} = 4.0 \times 10^8 \text{ J}.
\]

(b) Estimate the minimum area of the solar panel needed to provide 1.8 \times 10^8 J of energy in 2.0 hours.

(b) \[
\text{energy provided in 2 hours} = 7200 \times 900 \times \text{area}
\]

\[
\text{Therefore area} A = \frac{(4.0 \times 10^8 \text{ J})}{(7200 \text{ s} \times 1000 \text{ Js}^{-1})} = 55.6 \text{ m}^2.
\]
43. If a wave is 12 m high and has a wavelength of 30 m and a frequency of 0.2 s\(^{-1}\), estimate the power for each metre of the wave. (word estimate implies g = 10 ms\(^{-2}\))

\[
\text{Power} = \frac{1}{2} \rho g A^2 v
\]

\[
A = 6 \text{ m} \quad v = \lambda / T \quad 1/T = f
\]

\[
\text{Power} = \frac{1}{2} \rho g A^2 \lambda f
\]

\[
P = 0.5 \times 1020 \text{ kg m}^{-3} \times 10 \text{ m s}^{-2} \times 6^2 \text{ m}^2 \times 30 \text{ m} \times 0.1 \text{ s}^{-1}
\]

\[
= 550 \times 10^2 \text{ kg m}^2 \text{s}^{-3} = 550 \text{ kW per metre.}
\]

44. If a wave is 12 m high and has a wavelength of 25 m and a period of 8 s, estimate the power over each metre of wavefront and calculate the wave speed.

\[
\text{Wave speed} = \text{wavelength} / \text{period}
\]

\[
v = \lambda / T = 25 \text{ m} / 8 \text{ s} = 3.1 \text{ ms}^{-1}
\]

\[
\text{Power} = \frac{1}{2} \rho g A^2 v
\]

\[
= 0.5 \times 1020 \text{ kg m}^{-3} \times 10 \text{ m s}^{-2} \times 6^2 \text{ m}^2 \times 3.1 \text{ m s}^{-1}
\]

\[
= 5.74 \times 10^5 \text{ kg m}^2 \text{s}^{-3} = 574 \text{ kW per metre.}
\]

45. In a hydro-electric power station, water falls through a 75 m pipe at the rate of 1500 kg s\(^{-1}\).

How many megawatts of electric power could be produced by the power plant if it is 80% efficient?

\[
\text{Power} = 0.80 \times \Delta \text{PE/s} = 0.80 \text{ mgh}
\]

\[
= 0.80 \times 1500 \text{ kg s}^{-1} \times 9.8 \text{ ms}^{-2} \times 75 \text{ m} = 880 \text{ MW}
\]

46. A photovoltaic cell can produce an average 40 Wm\(^{-2}\) of electrical energy if it is directly facing the Sun at the equator. If a house has an electrical consumption of 75 kW, what would be the required surface area of cells needed to provide the power requirements of the household.

\[
A \times 40 \text{ Wm}^2 = 75000 \text{ W}
\]

\[
A = 1.9 \times 10^3 \text{ m}^2 \sim 2000 \text{ m}^2
\]

47. The following table shows the power generated by by a small wind turbine as a function of wind speed and radius of the blade. Plot graphs to show the linear relationships that exist between the power generated and these variables

<table>
<thead>
<tr>
<th>Power / W</th>
<th>Blade radius / m</th>
<th>Power / W</th>
<th>Wind speed / kmh(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.5</td>
<td>20</td>
<td>12.6</td>
</tr>
<tr>
<td>400</td>
<td>0.7</td>
<td>80</td>
<td>15.9</td>
</tr>
<tr>
<td>500</td>
<td>0.8</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>620</td>
<td>0.9</td>
<td>370</td>
<td>25.2</td>
</tr>
<tr>
<td>805</td>
<td>1.0</td>
<td>580</td>
<td>29.2</td>
</tr>
<tr>
<td>1020</td>
<td>1.1</td>
<td>610</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1020</td>
<td>35</td>
</tr>
</tbody>
</table>

![Graph showing power vs wind speed and blade radius](image)
48. How much solar radiation does one square metre of the Earth’s surface receive per day?

In one day, the solar radiation would be

\[ 170 \text{ W m}^{-2} \times 1 \text{ m}^2 \times 24 \text{ h} = 4080 \text{ W h} \]

For the land area of the USA, the solar radiation available over the total land surface is over 1017 kW h annually. This is about 600 times greater than the total energy consumption of the USA.

49. Given that the mean Sun-Earth distance is \( 1.5 \times 10^8 \) km and that the power received at the top of the Earth’s atmosphere is given by the solar constant, determine the total power generated by the Sun.

Every \( m^2 \) at an Earth–Sun mean distance receives \( 1.35 \text{ kW m}^{-2} \)

The surface area of a sphere = \( 4 \pi r^2 \)

Total power received = \[ 4 \pi (1.5 \times 10^{11} \text{ m})^2 \times 1.35 \times 10^{-3} \text{ W m}^{-2} = 3.8 \times 10^{26} \text{ W}. \]

50. The tungsten filament of a pyrometer (instrument for measuring high temperature thermal radiation) has a length of 0.50 m and diameter of \( 5.0 \times 10^{-5} \) m. The power rating is 60 W. Estimate the steady temperature of the filament. Assume that the radiation from the filament is the same as a perfect black body radiator at that steady temperature.

Power radiated = power received = 60 W

\[ 60 = P = A \sigma T^4 \]

The surface area of tungsten filament (cylinder) = \( 2 \pi rh \)

\[ = 2 \pi 	imes 5.0 \times 10^{-5} \text{ m} \times 0.5 \text{ m} = 1.57 \times 10^{-4} \text{ m}^2 \]

\[ \sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \]

\[ T = \sqrt[4]{\frac{60W}{1.57 \times 10^{-4} \text{ m}^2 \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}}} \]

\[ T = 1611 \text{ K} = 1600 \text{ K} \]

51. If one assumes that the Sun is a perfect black body with a surface temperature of 6000 K, calculate the energy per second radiated from its surface.

(4.55 \times 10^{26} \text{ W m}^{-2})

\[ \text{Energy per second} = P = A \sigma T^4 = 4\pi r^2 \sigma T^4 \]

\[ P = 4\pi \times (7 \times 10^8 \text{ m})^2 \times 5.7 \times 10^8 \text{ W m}^{-2} \text{ K}^{-4} \times 6000^4 \text{ K}^{-4} \]

\[ P = 4.55 \times 10^{26} \text{ W m}^{-2} \]

52. The solar power received on the surface of the Earth at normal incidence is about 1400 Wm^{-2}. Deduce that the power output per square centimetre of the Sun’s surface is about \( 7.5 \times 10^7 \) Wm^{-2}. Comment on some assumptions that have been made in determining this answer. (Take the Sun’s radius as \( 6.5 \times 10^8 \) m and the radius of the Earth’s orbit around the Sun as \( 1.5 \times 10^{11} \) m).

Some assumptions are: the Sun and the Earth act as perfect black bodies, that the Earth’s orbit around the Sun is circular rather than elliptical or all of the Sun’s radiation falls on a sphere of this radius, that the Sun and the Earth are uniform spheres, and that the Earth’s atmosphere absorbs no energy.

\[ \text{Energy per second} = P = A \sigma T^4 = 4\pi r^2 \sigma T^4 \]

This energy falls around a circular sphere equivalent to the Earth’s orbit around the Sun equal to \( 4 \pi r_e^2 \).

\[ \text{Therefore, the power received per square metre on the Earth will be a fraction of that radiated by the Sun.} \]

\[ \text{Power radiated by the Sun} = \frac{4\pi r_e^2}{4\pi r_s^2} \times 1400 \text{ Wm}^{-2} = 7.46 \times 10^7 \text{ Wm}^{-2} \]
53. The Sun is at 50° to the horizontal on a clear day. Estimate how much radiation from the Sun is absorbed per hour by an animal that has a total area exposed to the Sun of 2.0 m².

(Assume \( \sigma = 5.7 \times 10^{-8} \) W m\(^{-2}\) K\(^{-4}\) and the emissivity to be 0.8)

*Take the average temperature to be 300 K.*

Energy per second = \( P = eA \sigma T^4 \cos 50^0 \)

\[
P = 0.8 \times 2.0 \text{ m}^2 \times 5.7 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times 300^4 \text{ K}^4 \times \cos 50^0
\]

\[
P = 4.75 \times 10^2 \text{ W}
\]

This is the energy absorbed per second. Multiply by 3600

\[
P = 1.7 \times 10^6 \text{ W h}^{-1}
\]

54. Estimate the effective heat capacity of the land surface if the specific heat capacity of rock and 20% wet sand are 2000 J kg\(^{-1}\)K\(^{-1}\) and 1500 J kg\(^{-1}\)K\(^{-1}\) respectively and the thermal energy is captured in the top 2 m. (Make the density equal to 2000 kgm\(^{-3}\)).

\[
C_S = f \rho c h
\]

\( f = 0.3 \) (fraction of Earth covered by land),

\( \rho = \) the average density is 2000 kgm\(^{-3}\),

\( c = \) the average specific heat capacity could be 1750 J kg\(^{-1}\)K\(^{-1}\)

\( h = \) the depth of land that stores thermal energy.

So \( C_S = 0.3 \times 2000 \text{ kgm}^{-3} \times 1750 \text{ J kg}^{-1} \text{K}^{-1} \times 2 \text{ m} = 2.1 \times 10^6 \text{ J m}^{-2} \text{K}^{-1} \)

55. It takes \( 2 \times 10^{11} \) J of thermal energy to heat 50 m\(^2\) of the Earth by 10 K. Determine the surface heat capacity of the Earth.

\[
Q = m^2 C_s \Delta T \quad C_s = Q / \Delta T m^2
\]

\[
C_s = 2 \times 10^{11} \text{ J} / 50 \text{ m}^2 \times 10 \text{ K} = 4 \times 10^8 \text{ Jm}^2 \text{ K}^{-1}
\]

56. If the long-wave radiation flux from the surface of the Earth has an average value of 240 Wm\(^{-2}\) and the average temperature somewhere in the atmosphere is 255 K, determine the incoming and outgoing radiation of the Earth. Assume the global albedo is 0.3.

(Solar constant \( \alpha \) at a particular surface is defined as the amount of solar energy per second that falls on an area of 1m\(^2\) of the upper atmosphere perpendicular to the Sun’s rays, and its value is equal to 1.35 x 103 Wm\(^{-2}\)).

Incoming radiation = \((1 - \alpha) \times \) solar constant / 4

\[
= (1 - 0.3) \times 1.35 \times 10^3 \text{ Wm}^{-2} / 4 = 236.25 \text{ Wm}^{-2}
\]

Outgoing radiation = \( \sigma T_E^4 \)

\[
= 5.7 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (255)^4 \text{ K}^4 = 241 \text{ Wm}^{-2}
\]

These values are nearly equal to the average radiation flux value of 240 Wm\(^{-2}\).
57. By referring to Figures 1 and 2 answer the following questions.

(a) What is the difference between a black body radiator and a non-black body radiator.

(a) Black-body radiation is the radiation emitted by a “perfect” emitter. A nonblack body is not a perfect radiator of energy.

(b) Explain why a body at 1500 K is “red hot” whereas a body at 3000 K is “white hot”.

(b) The spectrum extends into the red region of the visible spectrum at 1500 K. It extends into the ultra-violet region at 3000 K.

(c) How can you use the information from the graphs to attempt to explain Stefan’s law?

(c) The total area under a spectral emission curve for a certain temperature T represents the total energy radiated per metre $^2$ per unit time $E$, and for that assigned temperature it has been found to be directly proportional to the fourth power $T^4$.

BTR: Stefan’s law: $P = e \sigma \epsilon T^4$ where $e$ is the emissivity of the surface of the body. The value of the emissivity is between zero and one, and equals one for a perfect black body. Bodies can, of course, lose heat by other mechanisms (conduction and convection), but at high temperature radiation becomes dominant.

(d) As the temperature increases, what changes take place to the energy distribution among the wavelengths radiated?

(d) The energy distribution of the wavelengths move into shorter wavelength regions while still being found in the infrared and visible regions.

58. A very long thin-walled glass tube of diameter 2.0 cm carries oil at a temperature 40 °C above that of the surrounding air that is at a temperature of 27 °C. Estimate the energy lost per unit length.

ANS:

$$P = 2\pi r \sigma (T^4 - T_0^4) = 2\pi \times 0.01 \times 5.67 \times 10^{-8} (340^4 - 300^4) = 18.75 = 19 \text{ Wm}^{-1}$$

59. (a) Estimate the mean surface temperature of the Earth if the Sun’s rays are normally incident on the Earth. Assume the Earth is in radiative equilibrium with the Sun. The Sun’s temperature is 6000 K and its radius is $6.5 \times 10^8$ m. The distance of the Earth from the Sun is $1.5 \times 10^{11}$m.

(a) Power from the Sun = $4\pi r_S^2 \alpha T_S^4$. Power received by the earth = the area on which the Sun’s radiation is normally incident / the total surface area on which the Sun’s radiation falls when the earth is $1.5 \times 10^{11}$ m from the Sun x the power radiated by the Sun.

$$= (\pi r_E^2 / 4\pi r^2) \times 4\pi r_S^2 \alpha T_S^4$$
If the earth is in radiative equilibrium with the Sun, the power received by the earth = the power radiated by the earth.

\[
4\pi r_E^2 \sigma T_E^4 = (\pi r_S^2 / 4\pi r^2) \times 4\pi r_S^2 \sigma T_S^4
\]

\[
T_E^4 = (r_S^2 / 4\pi r^2) \times T_S^4
\]

\[
T_E = T_S \times \sqrt{(r_S^2 / r^2)} = 6000 \times \sqrt{6.5 \times 10^8 / 3 \times 10^{11}} = 306 \text{ K} \]

(b) What assumptions have been made about the temperature obtained?

(b) Assumptions: both bodies are black bodies, no radiation is lost in the atmosphere, no heat is radiated by the earth's interior.

60. Estimate the effective heat capacity of the oceans if the specific heat capacity of water is 4200 J kg\(^{-1}\) K\(^{-1}\) and the thermal energy is captured in the top 50 m. (Make the density equal to 1030 kg m\(^{-3}\)).

\[
C_S = \rho c h
\]

\[
C_S = 0.7 \times 1000 \text{ kg m}^{-3} \times 4200 \text{ J kg}^{-1} \text{ K}^{-1} \times 50 \text{ m} = 2.1 \times 10^6 \text{ J m}^{-2} \text{ K}^{-1}.
\]

61. Suppose that the solar constant at the 25° S latitude belt increased by 20% for two years when the albedo was 0.3 and the temperature somewhere above in the atmosphere was 255 K. Determine the change in temperature for this time period.

6.6 K

62. (a) Calculate the total energy needed to convert 10 tonnes of ice at -40 °C to water at 16 °C.

(a) Specific heat of ice = 2.1 × 10^3 J kg\(^{-1}\) K\(^{-1}\)

Latent heat of fusion of ice = 3.34 × 10^5 J kg\(^{-1}\)

Specific heat capacity of water = 4180 × J kg\(^{-1}\) K\(^{-1}\)

\[
Q = mc\Delta T_{\text{ice}} + mL_{\text{f}} + mc\Delta T_{\text{water}}
\]

\[
= m[ L_{\text{f}} + c\Delta T_{\text{water}} + c\Delta T_{\text{ice}}]
\]

\[
= 1 \times 10^4 \text{ kg} [(2.1 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1} \times 40^0 \text{ K}) + 3.34 \times 10^5 \text{ J kg}^{-1} + (4180 \times \text{ J kg}^{-1} \text{ K}^{-1} \times 16^0 \text{ K})]
\]

\[
= 4.84 \times 10^9 \text{ J} = 5 \times 10^9 \text{ J}
\]

(b) If the ice has an area of 100 m\(^2\), estimate the depth of the ice.

(b) 10 tonnes = 10 000 kg. If we assume that 1 kg of water has a volume of 1 dm\(^3\) then the total volume would be 10 000 dm\(^3\) or 100 m\(^3\). Therefore, the depth of the ice would be 1 m because 100 m\(^2\) × 1 m = 100 m\(^3\).

(c) Now suppose this volume of water was increased in temperature by 4 °C, estimate the increase in volume of the water.

(c) \(\Delta V = \beta V_0 \Delta T = 210 \times 10^6 \text{ K}^{-1} \times 100 \text{ m}^3 \times 2 \text{ K} = 4.2 \times 10^2 \text{ m}^3 = 4.2 \text{ L}\).

63. (a) If the Sun supplied 1 kW m\(^{-2}\) to the ice in the previous question and the ice had an albedo of 0.90, estimate the time it would take for the ice to melt and reach 16 °C.

(a) Energy required = 4.84 × 10^9 J and the Sun supplies 1000 Js m\(^{-2}\).

The albedo is 0.90 so 90% of the radiation is reflected.

Energy supplied by the Sun = 100 Js m\(^{-2}\).

If this energy goes to heating the ice, then it will take:

\[
4.85 \times 10^9 \text{ J} / 100 \text{ Js}^{-1} \text{ m}^{-2} = 4.85 \times 10^7 \text{ s} = 1.54 \text{ years}
\]
(b) What assumptions have been made in this estimate?

(b) We have assumed that no heat was lost to the surroundings and that the ice
is not 1 m thick but rather infinitely thin.

64. Define the following terms
(a) energy the capacity to do work
(a) energy - the capacity to do work.

(b) energy density
(b) efficiency of an energy conversion process - ratio of the useful energy output
to the total energy input usually expressed as a percentage.

(c) efficiency of an energy conversion
(c) energy density - the amount of potential energy stored in a fuel per unit mass, or per unit volume depending on the fuel being discussed.

(d) albedo
(d) albedo (α) - (Latin for white) at a surface is the ratio between the incoming radiation and the amount reflected expressed as a coefficient or as a percentage.

(e) resonance
(e) resonance - when the frequency of the infrared radiation is equal to the frequency of vibration then resonance occurs.

(f) emissivity
(f) emissivity - the ratio of the amount of energy radiated from a material at a certain temperature and the energy that would come from a blackbody at the same temperature and as such would be a number between 0 and 1.

(g) surface heat capacity
(g) surface heat capacity Cs - the energy required to raise the temperature of a unit area of a planet’s surface by one degree Kelvin and is measured in Jm⁻²K⁻¹.

(h) the coefficient of volume expansion.
(h) coefficient of volume or cubical expansion β - the fractional change in volume per degree change in temperature and is given by the relation: \[ \Delta \tilde{\V} = \beta V_0 \Delta T \]
where \( V_0 \) is the original volume, \( \Delta \tilde{\V} \) is the volume change, \( \Delta T \) is the temperature change and \( \beta \) is the coefficient of volume expansion.

65. Describe the meaning of the following terms and give an example of each
(a) a thermodynamic cycle
(a) thermodynamic cycle - a process in which the system is returned to the same state from which it started. That is, the initial and final states are the same in the cyclic process.

(b) energy degradation
(b) energy degradation - when energy is transferred from one form to other forms, the energy before the transformation is equal to the energy after (Law of conservation of energy). However, some of the energy after the transformation may be in a less useful form. We say that the energy has been degraded.

(c) a fossil fuel
(c) fossil fuels - naturally occurring fuels that have been formed from the remains of plants and animals over millions of years. The common fossil fuels are peat,
coal, crude oil, oil shale, oil tar and natural gas.

(d) a renewable energy source
(d) renewable energy source - one that is permanent or one that can be replenished as it is used. Renewable sources being developed for commercial use include solar energy, biomass, wind energy, tidal energy, wave energy, hydroelectric energy and geothermal energy.

(e) a pump storage system
(e) pump storage systems - used in off-peak electricity demand periods. The water is pumped from low reservoirs to higher reservoirs during this period.

(f) a combined cycle gas turbine
(f) combined cycle gas turbines (CCGT) - a jet engine is used in place of the turbine to turn the generator. Natural gas is used to power the jet engine and the exhaust fumes from the jet engine are used to produce steam which turns the generator.

(g) an oscillating water column
(g) oscillating water column (OWC) - wave energy devices that convert wave energy to electrical energy. These can be moored to the ocean floor or built into cliffs or ocean retainer walls.

(h) blackbody radiation
(h) black-body radiation - the radiation emitted by a “perfect” emitter. The radiation is sometimes called temperature radiation because the relative intensities of the emitted wavelengths are dependant only on the temperature of the black body.

67. Outline the process of the natural greenhouse effect.

The natural greenhouse effect is a phenomenon in which the natural greenhouse gases absorb the outgoing long wave radiation from the earth and re-radiate some of it back to the earth. It is a process for maintaining an energy balancing process between the amount of long wave radiation leaving the earth and the amount of energy coming in from the sun. Provided that the Sun’s radiant energy remains constant and the percentage of greenhouse gases remains the same, then the established equilibrium will remain steady and the average temperature of the earth will be maintained at 16 °C.