Answers to test yourself questions

Topic 8

8.1 Energy sources

1 a Specific energy is the energy that can be extracted from a unit mass of a fuel while energy density is the energy that can be extracted from a unit volume of fuel.

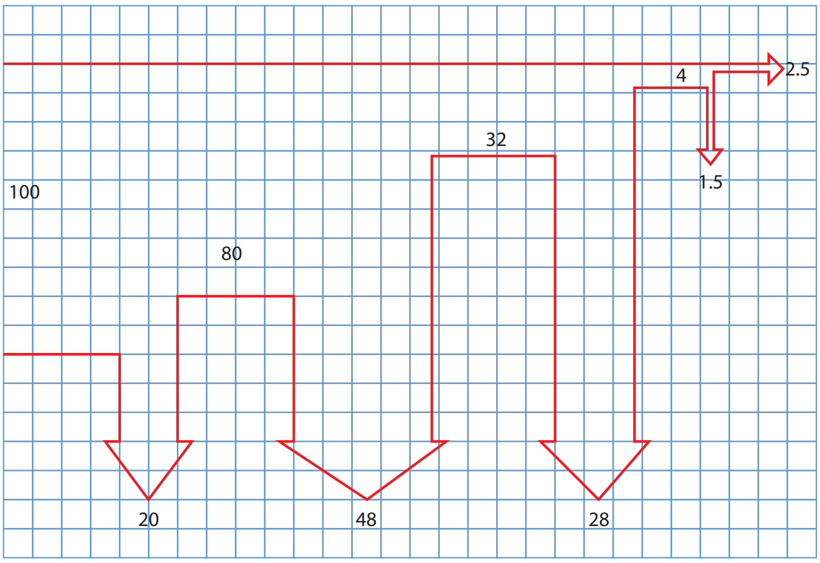
b The available energy is mgh. The energy density is the energy per unit volume that can be obtained and so $E_D = \frac{mgh}{V} = \frac{mgh}{\frac{m}{\rho}} = \rho gh = 10^3 \times 9.8 \times 75 = 7.4 \times 10^5\ \mathrm{J\,m^{-3}}$

2 a In 1 s the energy is 500 MJ.

b In one year the energy is $5.0 \times 10^8 \times 365 \times 24 \times 60 \times 60 = 1.6 \times 10^{16}$ J.

3 a The overall efficiency is $0.80 \times 0.40 \times 0.12 \times 0.65 = 0.025$.

b



4 a The energy produced by burning the fuel is $10^7 \times 30 \times 10^6 = 3.0 \times 10^{14}$ J. Of this 70% is converted to useful energy and so the power output is $P = \frac{0.30 \times 3.0 \times 10^{14}}{24 \times 60 \times 60} = 1.04 \times 10^9$ W.

b The rate at which energy is discarded is $P_{discard} = \frac{0.70 \times 3.0 \times 10^{14}}{24 \times 60 \times 60} = 2.43 \times 10^9$ W.

c Use $\frac{\Delta m}{\Delta t} c\Delta\theta = P_{discard}$ to get $\frac{\Delta m}{\Delta t} = \frac{P_{discard}}{c\Delta\theta} = \frac{2.43 \times 10^9}{4200 \times 5} = 1.2 \times 10^5\ \mathrm{kg\,s^{-1}}$.

5 In time t the energy used by the engine is $20 \times 10^3 \times t$. The energy available is $0.40 \times 34 \times 10^6$ J and so $20 \times 10^3 \times t = 0.40 \times 34 \times 10^6 \Rightarrow t = 680$ s. The distance travelled is then $x = vt = 9.0 \times 680 = 6.1$ km.

6 The useful energy produced each day is $E = Pt = 1.0 \times 10^9 \times 24 \times 60 \times 60 = 8.64 \times 10^{13}$ J. The energy produced by burning the coal is therefore $0.40 = \frac{8.64 \times 10^{13}}{E_c} \Rightarrow E_c = 2.16 \times 10^{14}$ J. So the mass of coal to be burned is $m = \frac{2.16 \times 10^{14}}{30 \times 10^6} = 7.2 \times 10^6$ kg per day.

7 a The fissionable isotope of uranium is U – 235. This is found in very small concentrations in uranium ore which is mostly U – 238. Enrichment means increasing the concentration of U – 235 in a sample of uranium.

b The moderator is the part of the nuclear reactor where neutrons released from the fission reactions slow down as a result of collisions with the atoms of the moderator. The temperature of the moderator can be kept constant with a cooling system that removes the excess thermal energy generated in the moderator.

c Critical mass refers to the least mass of uranium that must be present for nuclear fission reactions to be sustained. If the mass of uranium is too small (i.e. below the critical mass) the neutrons may escape without causing fission reactions.

8 a The reaction is ${}^{235}_{92}\text{U}+{}^{1}_{0}\text{n} \rightarrow {}^{140}_{54}\text{Xe} + {}^{94}_{38}\text{Sr} + 2\,{}^{1}_{0}\text{n}$. The mass difference is

$$\delta = (235.043\,992 - 92 \times 0.000549) + 1.008\,665$$
$$-\big((139.921\,636 - 54 \times 0.000549) + (93.915\,360 - 38 \times 0.000549) + 2 \times 1.008\,665\big)$$
$$= 0.198\,331 \text{ u}$$

And so the energy released is $E = 0.198331 \times 931.5c^2 \text{ MeV}c^{-2} = 185$ MeV.

b With N reactions per second the power output is $N \times 185 \text{ MeVs}^{-1}$. In other words, $N \times 185 \times 10^6 \times 1.6 \times 10^{-19} = 200 \times 10^6 \Rightarrow N = 6.8 \times 10^{18} \text{ s}^{-1}$.

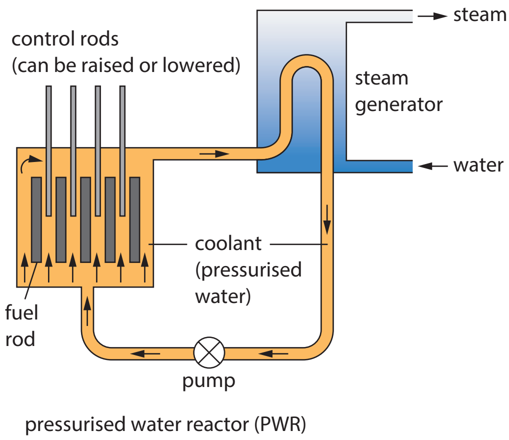
9 a One kilogram of uranium corresponds to $\frac{1000}{235} = 4.26$ moles and so $4.26 \times 6.02 \times 10^{23} = 2.57 \times 10^{24}$ nuclei. Each nucleus produces 200 MeV and so the energy produced by 1 kg (the energy density) is $2.57 \times 10^{24} \times 200 \times 10^6 \times 1.6 \times 10^{-19} \approx 8 \times 10^{13} \text{ J kg}^{-1}$.

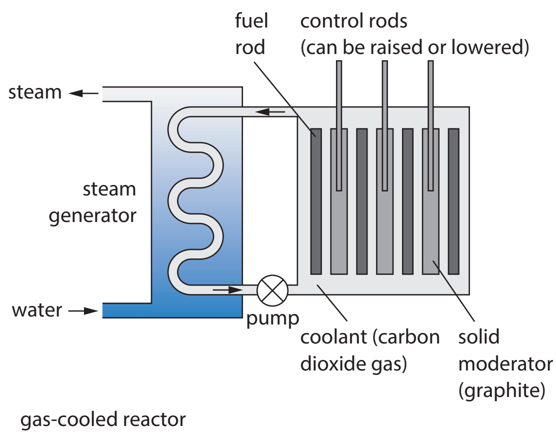
b $\frac{8 \times 10^{13}}{30 \times 10^{6}} = 2.7 \times 10^{6}$ kg

10 a The energy that must be produced in 1 s is $E = \frac{500 \times 10^6}{0.40} = 1.25 \times 10^9$ J. Hence the number of fission reactions per second is $\frac{1.25 \times 10^9}{200 \times 10^6 \times 1.6 \times 10^{-19}} = 3.9 \times 10^{19}$.

b The number of nuclei required to fission per second is 3.9×10^{19} which corresponds to $\frac{3.9 \times 10^{19}}{6.02 \times 10^{23}} = 6.5 \times 10^{-5}$ mol, i.e. a mass of $6.5 \times 10^{-5} \times 235 \times 10^{-3} = 1.5 \times 10^{-5} \text{ kg s}^{-1}$.

11





a i fuel rods are pipes in which the fuel (i.e. uranium – 235) is kept.

ii control rods are rods that can absorb neutrons. These are lowered in or raised out of the moderator so that the rate of reactions is controlled. The rods are lowered in if the rate is too high – the rods absorb neutrons so that these neutrons do not cause additional reactions. They raised out if the rate is too small leaving the neutrons to cause further reactions.

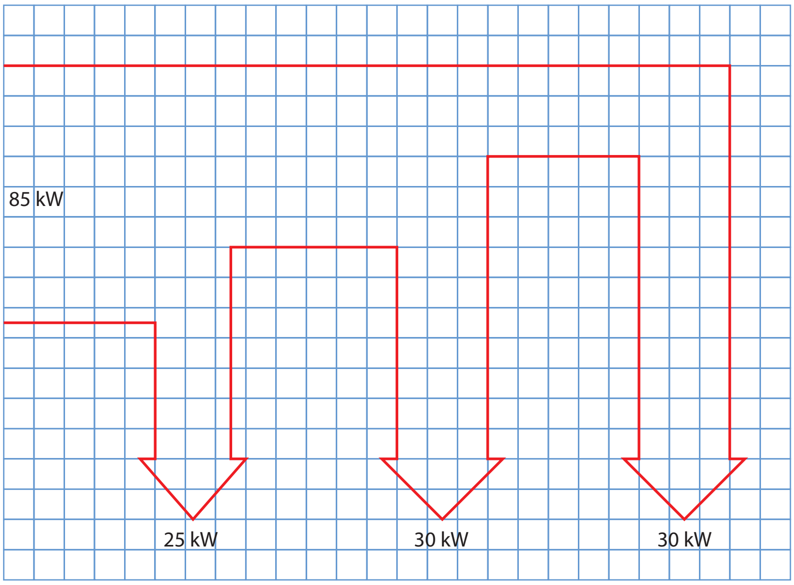
iii The moderator is the part of the nuclear reactor where neutrons released from the fission reactions slow down as a result of collisions with the atoms of the moderator. The temperature of the moderator can be kept constant with a cooling system that removes the excess thermal energy generated in the moderator.

b It is kinetic energy of the neutrons produced which is converted into thermal energy in the moderator as the neutrons collide with the moderator atoms.

12 A solar panel receives solar radiation incident on it and uses it to heat up water, i.e. it converts solar energy into thermal energy. The photovoltaic cell converts the solar incident on it to electrical energy.

13 **a** The power that must be supplied is 3.0 kW and this equals $700 \times A \times 0.70 \times 0.50$. Hence $700 \times A \times 0.70 \times 0.50 = 3.0 \times 10^3 \Rightarrow A = 12\ \text{m}^2$.

b



14 The power that is provided is $0.65 \times 240 \times A$ and this must equal $\dfrac{mc\Delta\theta}{\Delta t} = \dfrac{300 \times 4200 \times 35}{12 \times 60 \times 60}$.

Hence $0.65 \times 700 \times A = \dfrac{300 \times 4200 \times 35}{12 \times 60 \times 60} \Rightarrow A = 6.5\ \text{m}^2$.

15 The power incident on the panel is $600 \times 4.0 \times 0.60 = 1440\ \text{W}$. The energy needed to warm the water is $mc\Delta\theta = 150 \times 4200 \times 30 = 1.89 \times 10^7\ \text{J}$ and so $1440 \times t = 1.89 \times 10^7 \Rightarrow t = \dfrac{1.89 \times 10^7}{1440} = 1.31 \times 10^4\ \text{s} = 3.6\ \text{hr}$.

16 **a** From the graph this is about $T = 338\ \text{K}$

b $P = IA = 400 \times 2 = 800\ \text{W}$

c The useful power is the 320 W that is extracted. The efficiency is thus $\dfrac{320}{800} = 0.40$.

17 The power supplied at the given speed is (reading from the graph) 100 kW. Hence the energy supplied in 100 hrs is $100 \times 10^3 \times 1000 \times 60 \times 60 = 3.6 \times 10^{11}\ \text{J}$.

18 We look at the power formula for windmills, $P = \dfrac{1}{2}\rho A v^3$ to deduce:

a **i** the area will increase by a factor of 4 if the length is doubled and so the power goes up by a factor of 4,

ii the power will increase by a factor of $2^3 = 8$

iii the combined effect is $4 \times 8 = 32$

b Not all the kinetic energy of the wind can be extracted because not all the wind is stopped by the windmill (as the formula has assumed). In addition, there will be frictional losses as the turbines turn as well as losses due to turbulence.

19 Assumptions include:

i no losses of energy due to frictional forces as the turbines turn

ii no turbulence in the air

iii that all the air stops at the turbines so that the speed of the air behind the turbines is zero (which is impossible).

20 The power in the wind before hitting the turbine is $\frac{1}{2}\rho_1 A v_1^3$ and right after passing through the turbine is $\frac{1}{2}\rho_2 A v_2^3$ so the extracted power is $\frac{1}{2}\rho_1 A v_1^3 - \frac{1}{2}\rho_2 A v_2^3 = \frac{1}{2}\times\pi\times 1.5^2(1.2\times 8.0^3 - 1.8\times 3.0^3) \approx 2.0\text{ kW}$.

21 From $P = \frac{1}{2}\rho A v^3$ we get $25\times 10^3 = \frac{1}{2}\times 1.2\times A\times 9.0^3 \Rightarrow A = 57.16\text{ m}^2$ and so $\pi R^2 = 57.16 \Rightarrow R = 4.3\text{ m}$. The assumptions made are the usual ones (see question 19)

i no losses of energy due to frictional forces as the turbines turn
ii no turbulence in the air, and
iii that all the air stops at the turbines so that the speed of the air behind the turbines is zero (which is impossible).

22 The potential energy of a mass Δm of water is Δmgh and so the power developed is the rate of change of this energy i.e. $\frac{\Delta m}{\Delta t}gh = 500\times 9.8\times 40 = 1.96\times 10^5 \approx 2.0\times 10^5\text{ W}$.

23 The potential energy of a mass Δm of water is Δmgh and so the power developed is the rate of change of this energy i.e. $\frac{\Delta m}{\Delta t}gh = \rho\frac{\Delta V}{\Delta t}gh = \rho Qgh$.

24 The amount of electrical energy generated will always be less than the energy required to raise the water back to its original height. This is because the electrical energy generated is less than what theoretically could be provided by the water (because of various losses). So this claim cannot be correct.

25 **a** Coal power plant: chemical energy of coal → thermal energy → kinetic energy of steam → kinetic energy of turbine → electrical energy.
b hydroelectric power plant: potential energy of water → kinetic energy of water → kinetic energy of turbine → electrical energy.
c wind turbine: kinetic energy of wind → kinetic energy of turbine → electrical energy.
d nuclear power plant: nuclear energy of fuel → kinetic energy of neutrons → thermal energy in moderator → kinetic energy of steam → kinetic energy of turbine → electrical energy.

Chapter 8.2 Thermal energy transfer

26 **a** Energy has to be conserved so whatever energy enters the junction has to leave the junction and so the rates of energy transfer are the same.
b The temperature differences are not the same because X and Y have different thermal conductivity.

27 There is; in order to send the warm air that collects higher up in the room downwards.

28 Power is proportional to T^4 and so the ratio is $\left(\frac{900}{300}\right)^4 = 3^4 = 81$

29 **a** A black body is any body at absolute temperature T whose radiated power per unit area is given by σT^4. A black body appears black when its temperature is very low. It absorbs all the radiation incident on it and reflects none.
b A piece of charcoal is a good approximation to a black body as is the opening of a soft drink can.
c It increases by $\left(\frac{273+100}{273+50}\right)^4 \approx 1.8$

30 **a** The wavelength at the peak of the graph is determined by temperature and since the wavelength is the same so is the temperature.
b The ratio of the intensities at the peak is about $\frac{1.1}{1.9} \approx 0.6$.

31 We have that $e\sigma AT^4 = P \Rightarrow T = \sqrt[4]{\frac{P}{e\sigma A}}$ i.e. $T = \sqrt[4]{\frac{1.35\times 10^9}{0.800\times 5.67\times 10^{-8}\times 5.00\times 10^6}} = 278\text{ K}$.

32 a We must have that $\sigma AT^4 \propto \frac{1}{d^2} \Rightarrow T \propto \frac{1}{\sqrt{d}}$.

b Using our knowledge of propagation of uncertainties, we deduce that $\frac{\Delta T}{T} = \frac{1}{2}\frac{\Delta d}{d}$ and so $\frac{\Delta T}{T} = \frac{1}{2} \times 1.0\% = 0.005$. Hence, $\Delta T = 0.005T = 0.005 \times 288 = 1.4\,\text{K}$.

33 a Intensity is the power received per unit area from a source of radiation.

b $P = e\sigma AT^4$. $P = 0.90 \times 5.67 \times 10^{-8} \times 1.60 \times (273+37)^4 = 754\,\text{W}$. Assuming uniform radiation in all directions, the intensity is then $I = \frac{P}{4\pi d^2} = \frac{754}{4\pi (5.0)^2} = 2.4\ \text{W m}^{-2}$.

34 a Imagine a sphere centered at the source of radius d. The power P radiated by the source is distributed over the surface area A of this imaginary sphere. The power per unit area i.e. the intensity is thus $I = \frac{P}{A} = \frac{P}{4\pi d^2}$.

b We have assumed that the radiation is uniform in all directions.

35 a The peak wavelength is approximately $\lambda_0 = 0.65 \times 10^{-5}\,\text{m}$ and so from Wien's law: $\lambda_0 T = 2.9 \times 10^{-3}\,\text{Km}$ we find $T = \frac{2.9 \times 10^{-3}}{0.65 \times 10^{-5}} = 450\ \text{K}$.

b The curve would be similar in shape but taller and the peak would be shifted to the left.

36 a Albedo is the ratio of the reflected intensity to the incident intensity on a surface.

b The albedo of a planet depends on factors such as cloud cover in the atmosphere, amount of ice on the surface, amount of water on the surface and color and nature of the soil.

37 a The earth receives radiant energy from the sun and in turn radiates itself. The radiated energy is in the infrared region of the electromagnetic spectrum. Gases in the atmosphere absorb part of this radiated energy and reradiate it in all directions. Some of this radiation returns to the earth surface warming it further.

b The main greenhouse gases are water vapour, carbon dioxide and methane. See page 336 for sources.

38 a The energy flow diagram is similar to that in Fig. 8.10 on page 334.

b The reflected intensity is $350 - 250 = 100\,\text{Wm}^{-2}$ and so the albedo is $\frac{100}{350} = 0.29$.

c It has to be equal to that absorbed i.e. $250\,\text{Wm}^{-2}$.

d Use $e\sigma T^4 = I \Rightarrow T = \sqrt[4]{\frac{I}{e\sigma A}}$ i.e. (assuming a black body) $T = \sqrt[4]{\frac{250}{5.67 \times 10^{-8}}} = 258\ \text{K}$. You must be careful with these calculations in the exam. You must be sure as to whether the question wants you to assume a black body or not. Strictly speaking, in a model without an atmosphere the earth surface cannot be taken to be a black body – if it were no radiation would be reflected!

39 a The intensity radiated by the surface is I_1 and a fraction t of this escapes so we know that $I_3 = tI_1$. The intensity of radiation entering the surface is $(1-\alpha)\frac{S}{4} + \alpha I_1 + I_2$. This must equal the intensity of radiation leaving the surface which is I_1: $(1-\alpha)\frac{S}{4} + \alpha I_1 + I_2 = I_1$. The intensity of radiation entering the atmosphere is $(1-\alpha)I_1$ and that leaving it is $2I_2 + I_3$. Hence $2I_2 + I_3 = (1-\alpha)I_1$. So we have to solve the equations (we used $I_3 = tI_1$)

$$(1-\alpha)\frac{S}{4} + \alpha I_1 + I_2 = I_1$$

$$2I_2 + tI_1 = (1-\alpha)I_1$$

These simplify to

$$(1-\alpha)\frac{S}{4} + I_2 = (1-\alpha)I_1$$

$$2I_2 = (1-\alpha-t)I_1 \Rightarrow I_2 = \frac{(1-\alpha-t)}{2}I_1$$

Hence

$$(1-\alpha)\frac{S}{4}+\frac{(1-\alpha-t)}{2}I_1=(1-\alpha)I_1$$

$$(1-\alpha)\frac{S}{4}=(1-\alpha)I_1-\frac{(1-\alpha-t)}{2}I_1$$

$$(1-\alpha)\frac{S}{4}=\frac{(1-\alpha+t)}{2}I_1$$

$$I_1=\frac{2}{1-\alpha+t}(1-\alpha)\frac{S}{4}$$

Therefore, $I_2=\frac{1-\alpha-t}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}$ and $I_3=\frac{2t}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}$ as required.

b The intensity entering is $\frac{S}{4}$. The intensity leaving is $\alpha\frac{S}{4}+I_3+I_2$. The intensity leaving simplifies to

$$\alpha\frac{S}{4}+\frac{2t}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}+\frac{1-\alpha-t}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}=\frac{S}{4}\left(\alpha+(1-\alpha)\frac{2t}{1-\alpha+t}+(1-\alpha)\frac{1-\alpha-t}{1-\alpha+t}\right)$$

$$=\frac{S}{4}\left(\alpha+(1-\alpha)\frac{1-\alpha+t}{1-\alpha+t}\right)$$

$$=\frac{S}{4}(\alpha+(1-\alpha))$$

$$=\frac{S}{4}$$

c The intensity radiated by the surface is $I_1=\frac{2}{1-\alpha+t}(1-\alpha)\frac{S}{4}$ and must equal σT^4, where T is the surface temperature. Hence

$$\frac{2}{1-\alpha+t}(1-\alpha)\frac{S}{4}=\sigma T^4$$

$$t=\frac{2(1-\alpha)\frac{S}{4}}{\sigma T^4}-1+\alpha$$

$$t=\frac{2(1-0.30)\times 350}{5.67\times 10^{-8}\times 288^4}-1+0.30$$

$$t\equiv 0.556$$

d i Let an intensity I be incident on the atmosphere of emissivity e. An amount eI will be absorbed and reradiated, an amount αI will be reflected and an amount tI will be transmitted. By energy conservation we have that $I=eI+\alpha I+tI$ from which $e=1-\alpha-t$ as required.

ii We equate $I_2=\frac{1-\alpha-t}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}$ to $e\sigma T^4$ where T is the atmosphere temperature to get (recall that $e=1-\alpha-t$)

$$e\sigma T^4=\frac{1-\alpha-t}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}$$

$$\sigma T^4=\frac{1}{1-\alpha+t}\times\frac{(1-\alpha)S}{4}$$

$$T=\sqrt[4]{\frac{1}{1-0.30+0.556}\times\frac{(1-0.30)\times 350}{5.67\times 10^{-8}}}$$

$$T=242\text{ K}$$

40 Radiation is a main mechanism to both the atmosphere and to space. In addition there is conduction to the atmosphere, as well as convection.

41 **a** Dry sub – tropical land has a high albedo, around 0.4 whereas a warm ocean has an albedo of less than 0.2.
b Radiation and convection currents are the main mechanisms.
c Replacing dry land by water reduces the albedo of the region. Reducing the albedo means that less radiation is reflected and more is absorbed and so an increase in temperature might be expected. The increase in temperature might involve additional evaporation and so more rain.

42 The rate of evaporation from water depends on the temperature of the water and the temperature of the surrounding air. These are both higher in the case of the tropical ocean water and evaporation will be more significant in that case.

43 There is more evaporation in region **b** implying that it is both warmer and wet. The fact that region **b** is warmer is further supported by the somewhat greater conduction which would be expected if the difference in temperature between the atmosphere and the land were larger.

44 We have that the original average albedo of the area was $0.6\times 0.10+0.4\times 0.3=0.18$ and the new one is $0.7\times 0.10+0.3\times 0.3=0.16$ for a reduction in albedo of 0.02. Hence the expected temperature change is estimated to be 2°C.