Questions

1 Consider a scheme in which thermal energy is extracted from the ocean. Some of the extracted energy is used to perform mechanical work (run the ship) and the rest is discarded back into the ocean. Why will this not work?

2 Explain what is meant by *degradation of energy*. Give one example of energy degradation.

3 (a) Define *energy density* of a fuel.
(b) Estimate the energy density of water that falls from a waterfall of height 75 m and is used to drive a turbine.

4 A power plant produces 500 MW of power.
(a) How much energy is produced in one second? Express your answer in (i) joules, (ii) kWh and (iii) MWh.
(b) How much energy (in joules) is produced in one year?

5 A power plant operates in four stages. The efficiency in each stage is 80%, 40%, 12% and 65%.
(a) What is the overall efficiency of the plant?
(b) Make a Sankey diagram for the energy flow in this plant.

6 A coal power plant with 30% efficiency burns 10 million kilograms of coal a day. (Take the heat of combustion of coal to be 30 MJ kg^{-1}.)
(a) What is the power output of the plant?
(b) At what rate is thermal energy being discarded by this plant?
(c) If the discarded thermal energy is carried away by water whose temperature is not allowed to increase by more than 5 °C, calculate the rate at which water must flow away from the plant.

7 One litre of gasoline releases 35 MJ of energy when burned. The efficiency of a car operating on this gasoline is 40%. The speed of the car is 9.0 m s^{-1} when the power developed by the engine is 20 kW. Calculate how many kilometres the car can go with one litre of gasoline when driven at this speed.

8 A coal-burning power plant produces 1.0 GW of electricity. The overall efficiency of the power plant is 40%. Taking the energy density of coal to be 30 MJ kg^{-1}, calculate the amount of coal that must be burned in one day.

9 In the context of nuclear fission reactors, state what is meant by
(a) uranium enrichment;
(b) moderator;
(c) critical mass.

10 (a) Calculate the energy released in the fission reaction

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n$$

(b) How many fission reactions per second must take place if the power output is 200 MW? (The atomic masses are: uranium-235, $^{235}_{92}U = 235.043\,923$ u; xenon-140, $^{140}_{54}Xe = 139.921\,636$ u; strontium-94, $^{94}_{38}Sr = 93.915\,360$ u; neutron, $^{1}_{0}n = 1.008\,665$ u.)

11 The energy released in a typical fission reaction involving uranium-235 is 200 MeV.
(a) Calculate the energy density of uranium-235.
(b) How much coal (heat of combustion 30 MJ kg^{-1}) must be burned in order to give the same energy as that released in nuclear fission with 1 kg of uranium-235 available?

12 (a) A 500 MW nuclear power plant converts the energy released in nuclear reactions into electrical energy with an efficiency of 40%. Calculate how many fissions of uranium-235 are required per second. Take the energy released per reaction to be 200 MeV.
(b) What mass of uranium-235 is required to fission per second?

13 (a) Make a schematic diagram of a fission reactor, explaining the role of (i) fuel rods, (ii) control rods and (iii) moderator.
(b) In what form is the energy released in a fission reactor?

14 By looking up appropriate sources, write an essay about the problem of radioactive waste disposal.

15 Distinguish between a solar panel and a photovoltaic cell.

16 The typical energy of photons in the visible spectrum is 2 eV. Explain why a semiconductor with an energy gap between the valence and conduction bands of more than 2 eV would not be suitable in a photovoltaic cell.

17 Sunlight of intensity 700 W m^{-2} is captured with 70% efficiency by a solar panel, which then sends the captured energy into a house with 50% efficiency.

(a) If the house loses thermal energy through bad insulation at a rate of 3.0 kW, find the area of the solar panel needed in order to keep the temperature of the house constant.

(b) Make a Sankey diagram for the energy flow.

18 A solar heater is to heat 300 L of water initially at 15 °C to a temperature of 50 °C in a time of 12 hours. The amount of solar radiation falling on the collecting surface of the solar panel is 240 W m^{-2} and is collected at an efficiency of 65%. Calculate the area of the collecting panel that is required.

19 A solar heater is to warm 150 kg of water by 30 K. The intensity of solar radiation is 6000 W m^{-2} and the area of the panels is 4.0 m^2. The specific heat capacity of the water is 4.2×10^3 J kg^{-1} K^{-1}. Estimate the time this will take, assuming a solar panel efficiency of 60%.

20 The graph in Figure 1.20 shows the variation with incident solar power *P* of the temperature of a solar panel used to heat water when thermal energy is extracted from the water at a rate of 320 W. The area of the panel is 2.0 m^2 and the intensity of the solar radiation incident on the panel is 400 W m^{-2}. Calculate

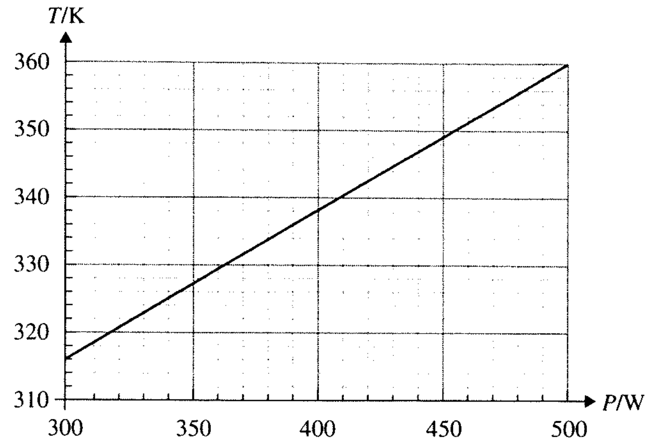

Figure 1.20 For question 20.

(a) the temperature of the water;

(b) the power incident on the panel;

(c) the efficiency of the panel.

21 The graph in Figure 1.21 shows the power curve of a wind turbine as a function of the wind speed. If the wind speed is 10 m s^{-1}, calculate the energy produced in the course of one year, assuming that the wind blows at this speed for 1000 hours in the year.

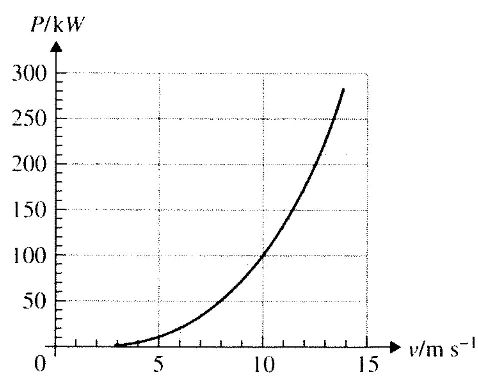

Figure 1.21 For question 21.

22 State the expected increase in the power extracted from a wind turbine when

(a) the length of the blades is doubled;

(b) the wind speed is doubled;

(c) both the length of the blades and the wind speed are doubled.

(d) Outline reasons why the actual increase in the extracted power will be less than your answers.

23 Wind of speed v is incident on the blades of a wind turbine. The blades present the wind with an area A.

(a) Deduce that the maximum theoretical power that can be extracted is given by

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

(b) State any assumptions made in deriving the relation in (a).

24 Air of density 1.2 kg m^{-3} and speed 8.0 m s^{-1} is incident on the blades of a wind turbine. The radius of the blades is 1.5 m. Immediately after passing through the blades, the wind speed is reduced to 3.0 m s^{-1} and the density of air is 1.8 kg m^{-3}. Calculate the power extracted from the wind.

25 Calculate the blade radius of a wind turbine that must extract 25 kW of power out of wind of speed 9.0 m s^{-1}. The density of air is 1.2 kg m^{-3}. State any assumptions made in this calculation.

26 Find the power developed when water in a waterfall with a flow rate of 500 L s^{-1} falls from a height of 40 m.

27 Water falls from a vertical height h at a flow rate (volume per second) Q. Deduce that the maximum theoretical power that can be extracted is given by $P = \rho Q g h$.

28 A student explaining pumped storage systems says that the water that is stored at a high elevation is allowed to move lower, thus producing electricity. Some of this electricity is used to raise the water back to its original height, and the process is then repeated. What is wrong with this statement?

29 (a) Supply the details for the derivation of the equation

$$\frac{P}{L} = \frac{\rho g A^2 v}{2}$$

for a wave with a square profile.

(b) Calculate the power per unit wavefront length that can be obtained from deep-sea waves of amplitude 5.0 m and wave speed $v = 4.8\,m\,s^{-1}$.

(c) What wavefront length is required for a total power output of 1.0 MW.

30 Describe the operation of an oscillating water column (OWC) device. State the main advantage of the OWC device.

31 Make an annotated energy flow diagram showing the energy changes that are taking place in each of the following:

(a) a conventional electricity-producing power station using coal;
(b) a hydroelectric power plant;
(c) an electricity-producing wind turbine;
(d) an electricity-producing nuclear power station.

HL only

32 Sunlight of intensity 800 W m^{-2} is captured by a tank containing 100 kg of water with an efficiency of 80%. The tank is rectangular in shape and has dimensions $1.0 \times 1.0 \times 0.10\,m^3$. It has walls of thickness 5.0 mm. The surrounding air has a temperature of 20 °C. Assume that the tank is well insulated from all sides except the top surface (of area 1.0 m^2). The material of the tank has a thermal conductivity of $k = 0.30\,W\,m^{-1}\,K^{-1}$, its density is 1200 kg m^{-3} and its specific heat capacity is 450 J kg^{-1} K^{-1}.

The rate of flow of thermal energy through a surface of area A and thickness x separated by temperatures T_1 and T_2 is given by

$$\frac{\Delta Q}{\Delta t} = kA\frac{T_1 - T_2}{x}$$

(a) Calculate the mass of the tank.
(b) By equating the energy received from the sunlight to the thermal energy lost by conduction to the surrounding air, estimate the final temperature of the water.

(c) Find the heat capacity, C, of the tank–water system.

(d) Show that the temperature T of the water in °C is increasing at a rate $\frac{\Delta T}{\Delta t}$ that can be found from the equation

$$C\frac{\Delta T}{\Delta t} = AI_{in} - kA\frac{T-20}{x}$$

where I_{in} is the intensity of sunlight captured by the tank, C is the heat capacity of the system, k is the thermal conductivity of the tank, A is the area of the top surface of the tank, and x is the thickness of the tank wall.

(e) Evaluate the rate of temperature increase when the temperature is the average of the initial temperature of 20 °C and the final temperature you found in part (b).

(f) Assuming that the temperature is increasing at this rate, calculate how long it will take the water to reach its final temperature.