OPTION P

Environmental Physics

Introduction

These Study Notes concentrate on the physics of many aspects of environmental concern. A full study of the topics considered here would have to take into account more than just the physics of the topic. For example, many geographical factors have to be considered. A solution to a problem on a remote island may be totally inappropriate in Singapore. Similarly, an area which historically is dependent on coal may find it much more difficult to persuade a local council to allow a wind farm to be erected than one where there is no such dependence. An environmentally friendly solution to a country's energy problems has to start from the present situation in the country. It is unrealistic to assume that a new, utopian system can somehow be installed overnight.

It is also unrealistic to consider problems without economic constraints and there is more to economics than the simple matter of how much something costs. For example, in building a power station, the relation between running costs and capital costs is critical. At times of low interest rates it makes more economic sense to increase capital spending if, thereby, running costs can be reduced. The opposite is true at times of high interest rates as repayment of interest can then be a crippling burden on any project. Another crucial economic consideration is the ready availability of cheap oil, gas and coal supplies on the world market. Many promising schemes for renewable energy are at present totally uneconomical because of these abundant energy supplies. As the supply of fossil fuels diminishes, however, the opportunity for renewable energy will increase, but this will probably take considerably longer than expected. Coal is still readily available and the oil companies are still making discoveries of oil and natural gas. However, they do not give much publicity to their discoveries as this can easily have an adverse effect, for them, on the world oil price.

P1. Power Sources

1 (a) *Candidates should be able to show an understanding of the term solar constant and use it to solve problems.*

1 (b) *Candidates should be able to show an understanding of the geographical variation of solar intensity at the Earth's surface.*

By far the most important source of power for the Earth is the Sun. The Sun radiates energy at the rate of 3.9×10^{26} joules per second, that is, a power of 3.9×10^{26} watts. Most of this power, which is in the form of electromagnetic radiation in the ultraviolet, visible and infra-red regions, travels off into deep space but a small fraction (less than one billionth) of it comes in the direction of the Earth and keeps the Earth's surface at a mean temperature of about 290 K (or 17 °C). In the absence of the Sun, the Earth would cool down rapidly as a result of the energy it radiates out into space. The total power from the Sun which is intercepted by the Earth is approximately 1.8×10^{17} W. The area of the disc of the Earth (Fig. 1.1), over which this power is distributed is $1.3 \times 10^{14}\,\mathrm{m}^2$, so the power supplied per unit area is $1400\,\mathrm{W\,m^{-2}}$. This figure is called the *solar constant* and is defined as the power incident normally per unit area above the Earth's atmosphere.

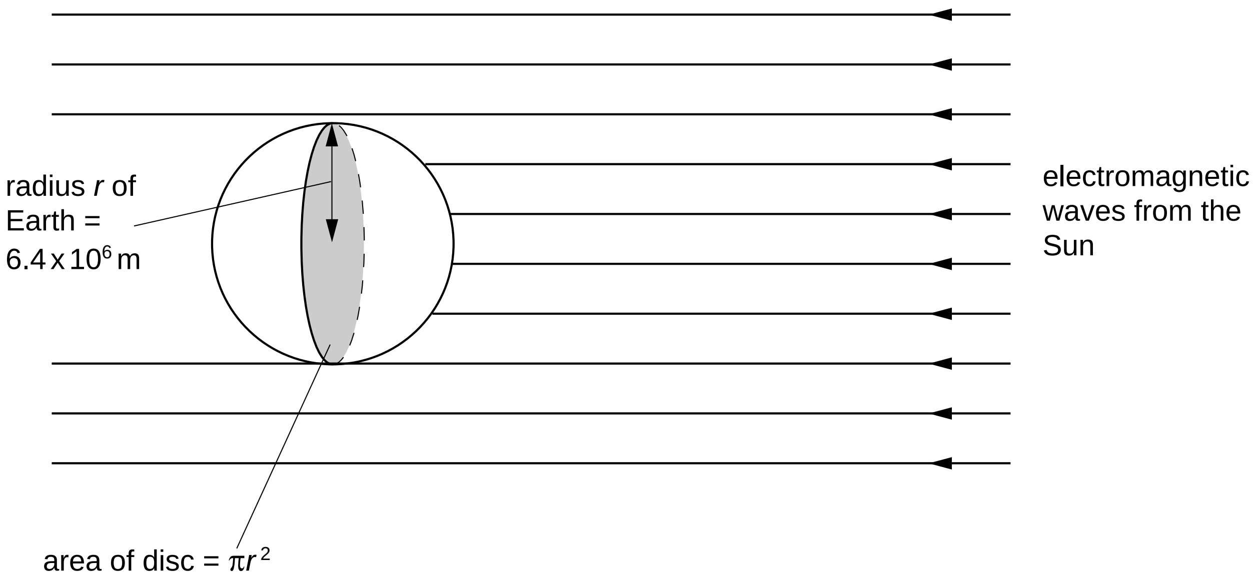

Fig. 1.1

The solar constant does actually vary. The distance from the Sun to the Earth changes during a year because the shape of the Earth's orbit is elliptical rather than circular. The Earth is nearest to the Sun in January and furthest from it in July.

The fraction of this virtually inexhaustible supply of power which is available to us depends on several factors:

(i) fraction reflected. The sea and the land both reflect some of the energy arriving but the most important reflector is the cloud cover. This obviously varies from place to place and from time to time.

(ii) atmospheric absorption. The thickness of the atmosphere through which the power has to pass depends on which part of the Earth is being considered. Since the Earth is rotating, the time of day also affects the intensity of the power (Fig. 1.2).

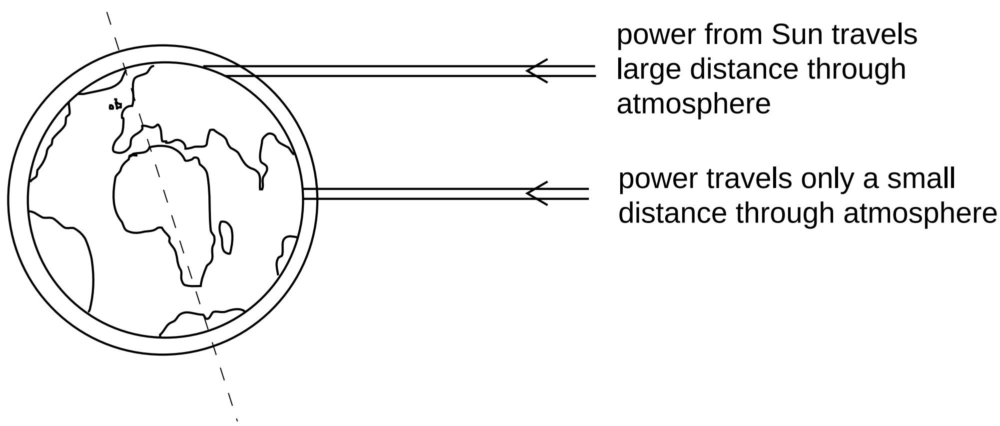

Fig. 1.2

(iii) latitude. Fig. 1.3 shows 800 W of power arriving at the Earth's surface at the equator when the Sun is overhead. It heats one square metre of the Earth. A similar 800 W of power arriving at a latitude θ is spread out over a larger area, given by $(1/\cos\theta)\,\mathrm{m}^2$.

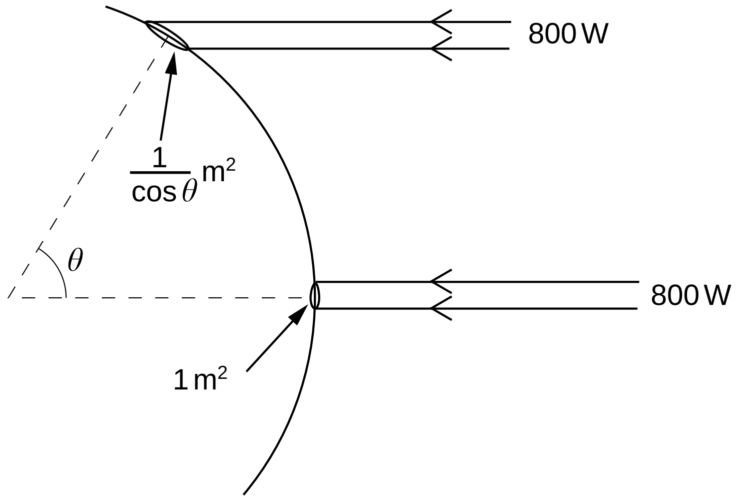

Fig. 1.3

This is the fundamental reason why the polar regions of the Earth are much cooler than the tropics.

(iv) tilt of the Earth's axis. This is related to (iii) and, in an extreme case, the North pole does not receive any direct radiation from the Sun during its long winter. Time of year therefore affects the power per square metre of surface. It also affects the fraction of the day during which energy is available from the Sun because sunrise is earlier and sunset is later during the summer.

1 (c) Candidates should be able to identify and explain the main components of the structure of solar cells and solar panels.

1 (d) Candidates should be able to show an appreciation that solar cells produce electrical energy whereas solar panels produce thermal energy.

Once energy from the Sun has reached the Earth's surface, the problem is how to make use of that energy. The answer at a basic level is that the energy warms the Earth directly. Unfortunately, this natural warming is not always provided where it is wanted. The Sahara desert is warmed very effectively by the Sun during the daytime but not many people live there because it is so hot and dry. On the other hand, in Britain during the winter not enough heat is provided directly from the Sun for most people's comfort so extra supplies would then be very welcome. In some situations, these extra supplies are provided in part either by solar cells, which produce electrical energy, or by solar panels, which produce warm water.

Solar cells are made from thin sheets of a semiconductor material such as silicon. Two different types of the material are used, p-type, doped to give it positive charge carriers and n-type, in which the charge carriers are negative. These cells are sometimes called photo-voltaic (PV) cells and the construction is shown in Fig. 1.4.

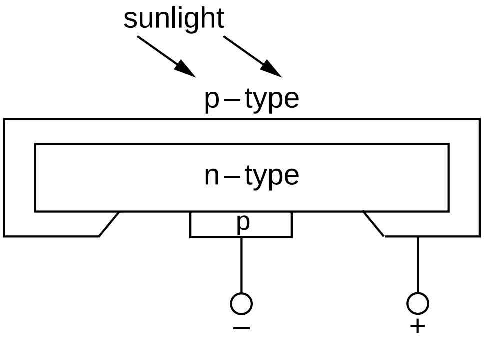

Fig. 1.4

A solar cell such as this gives an e.m.f. of only 0.6 V and even in full sunlight it requires 50 cm^2 of surface area exposed to sunlight in order to generate a current of one ampere. Appreciable power output therefore requires a large number of cells and corresponding expense. Solar cells are only about 10% efficient but rapid developments in solar cell technology have greatly reduced costs so that, in the long term, there are good prospects for greater general use of solar cells. At present, they tend to be used where only a small output power is required, such as in a calculator, or in remote places, such as for a satellite or for a navigation beacon. A practical array of solar cells is shown in Fig. 1.5.

Fig. 1.5

Solar panels are much less sophisticated. They consist basically of a coiled tube containing water with anti-freeze in it. The tube is placed in a flat box beneath a sheet of glass as shown in Fig. 1.6(a). A cross-section of the panel is shown in Fig. 1.6(b).

The whole panel may be 1.5 m x 1.0 m in size and be placed on a south-facing roof (in the northern hemisphere).

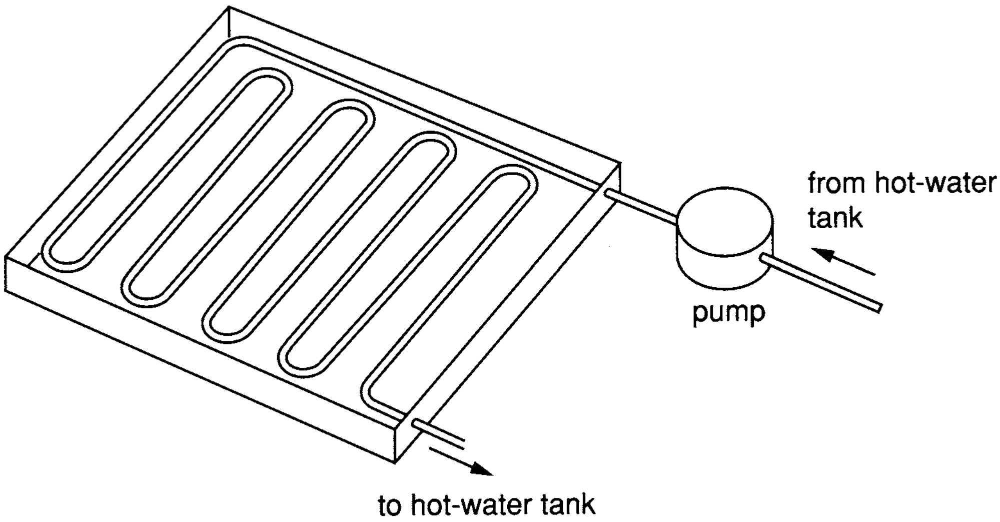

Fig. 1.6(a)

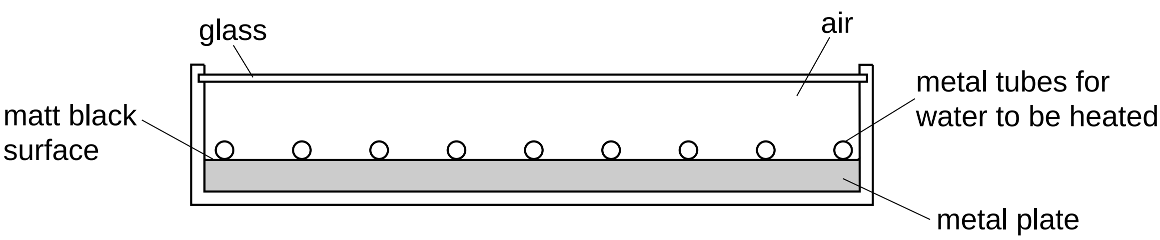

Fig. 1.6(b)

When placed in the sun, the water in the metal pipes in the solar panel warms up and, when hot enough, it can be pumped indoors where its thermal energy can be transferred to water in a hot-water tank. The pump for these systems requires electrical energy to operate it so this reduces their efficiency. They produce more useful thermal energy in the summer than in the winter because the amount of sunlight is then greater. For this reason, they have been used quite successfully for warming the water in swimming pools.

With both solar cells and solar panels, it can be an advantage to rotate the unit so that it is directly facing the Sun. However, this makes the system more expensive to install. If a static system is used, then it is advantageous for it to face south in the northern hemisphere and to be set at an angle to the horizontal so that, at mid-day, the unit is normal to the sunlight. Fig. 1.7 shows how the radiant power input per unit area to such a system may vary with time.

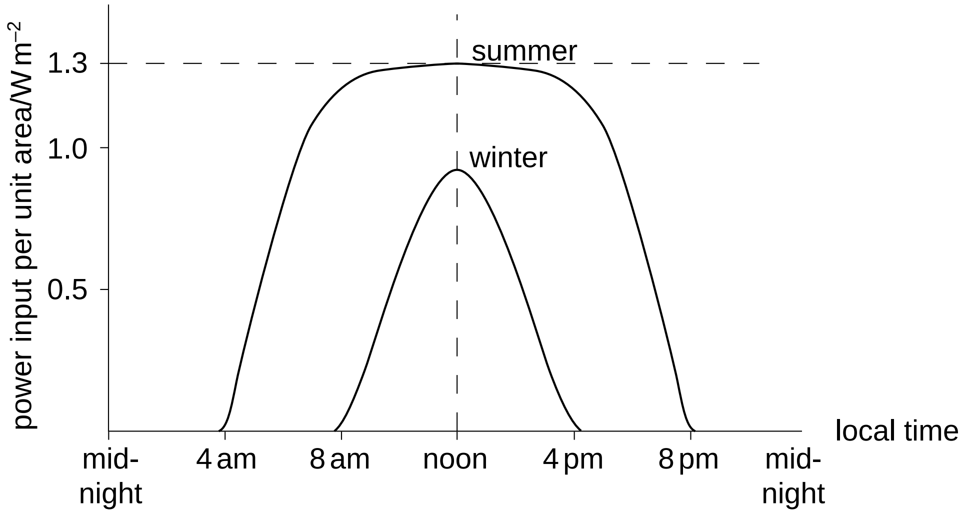

Fig. 1.7

The figures are for a system facing south in Penzance, England latitude 50°, with the panel at an angle of 30° to the horizontal. The area under each of these graphs gives the total energy input, and comparison between the two graphs shows clearly how much less total energy output might be obtained during the winter.

1 (e) *Candidates should be able to distinguish between the terms resources and reserves.*

1 (f) *Candidates should be able to state the different types of fossil fuel and show an understanding that these fuels are abundant yet finite.*

Some of the energy which has been supplied by the Sun during countless earlier years has been responsible for producing large quantities of coal, peat, oil and natural gas. Initially, these substances were living animals or plants and they have undergone incomplete decay followed in most cases by the application of pressure from overlying rocks. These fuels are called *fossil fuels* and they are deposited in various quantities in many different places around the world. Between them, the deposits constitute the total *resources* of the world's fossil fuels. One estimate of the total resources of the world puts the figure at 10^{23} J. This figure has only an order of magnitude value as many of the world's resources have probably not yet been discovered. Even those resources which have been discovered are very difficult to quantify accurately. (For comparison, the annual energy consumption in Britain is about 10^{19} J. The entire world's resources are equivalent to the energy which the Sun radiates in less than one millisecond or which it supplies to the Earth in about a week.)

Many of the Earth's resources are, at present, uneconomical to use. For instance, in Canada there are huge deposits of tar sands, from which the removal of sand and the extraction of oil is possible but too expensive while other, cheaper, sources of oil are available. The resources of the Earth which can be extracted economically are called *reserves* and again it is impossible to quote the value of the Earth's reserves with any accuracy. The economic climate is continually changing and new discoveries of oil and new techniques of extraction mean that the figure changes frequently. Major political upheavals, such as the 1973 oil crisis or the Gulf War, also have an effect on what is included in the Earth's reserves.

1 (g) *Candidates should be able to state the principles of the fission process.*

If a neutron is absorbed by a nucleus of certain isotopes, its effect is to render the nucleus completely unstable. This is illustrated in Fig. 1.8, where a neutron is shown colliding with a $^{235}_{92}U$ nucleus.

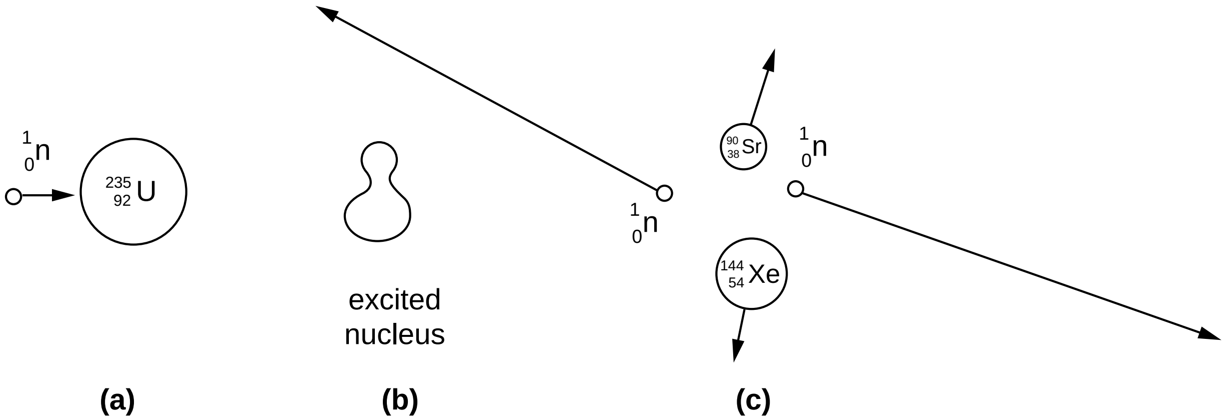

Fig. 1.8

The resulting $^{236}_{92}U$ nucleus is very unstable and, usually within a microsecond, undergoes fission. That is, it splits up into two major parts and additionally, releases some more neutrons. This explosion of a nucleus, like most explosions, is rather unpredictable in what particular pieces are emitted. However, one possible nuclear equation for the fission process is

$$^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{54}Xe + {}^{90}_{38}Sr + 2\,{}^{1}_{0}n + \text{energy.}$$

Four points related to this equation need to be considered.

(i) The equation represents a process which is used in all nuclear power stations and nuclear bombs.

(ii) The amount of energy released from this single nuclear fission is of the order of a million times greater than the energy released by the chemical action of a carbon atom being “burned” to form a carbon dioxide molecule. The mass of fuel required by a nuclear power station is therefore very much smaller than the mass of fuel required by a coal-fired power station.

(iii) More neutrons are produced by the process than are needed to start it. This gives rise to the possibility of a chain reaction, in which the number of nuclei undergoing fission increases. In a nuclear bomb explosion, the rate at which fission processes take place increases very rapidly with an enormous release of energy. In a nuclear reactor, the chain reaction is controlled in order to maintain a steady rate.

(iv) The strontium and xenon atoms produced by the fission reaction above are called the fission products. These fission products are highly radioactive and in a nuclear reactor are initially contained within the fuel rods. After a particular fuel rod is removed from a reactor in Britain, it is sent by rail in a very strong container to Sellafield, Cumbria. There, the non-radioactive parts of the fuel rods are separated from the parts which are radioactive and the radioactive parts are stored in large tanks. Since the half-life of some of the radioactive materials is very long, the intention is to solidify the material and bury it deep underground.

1 (h) *Candidates should be able to explain the role of fuel rods, moderator, coolant, control rods and the reactor vessel in a nuclear reactor.*

Fig. 1.9 illustrates in cross-section the structure of one type of nuclear reactor. All of the radioactive parts of the reactor are contained within the reactor pressure vessel. This is surrounded by a thick, concrete shield. The pressure vessel and concrete shield prevent leakage of radioactive material and provide shielding from radiation. The fission process takes place in the fuel rods, which therefore heat up. To prevent them from melting, and in order to get useful energy out of the reactor, a coolant is blown through the reactor core. Different coolants are used in different types of reactor. Many of the reactors in Britain use carbon dioxide as the coolant. As is shown in Fig. 1.9, the hot carbon dioxide, when it leaves the reactor, is used to produce high pressure steam in a heat exchanger.

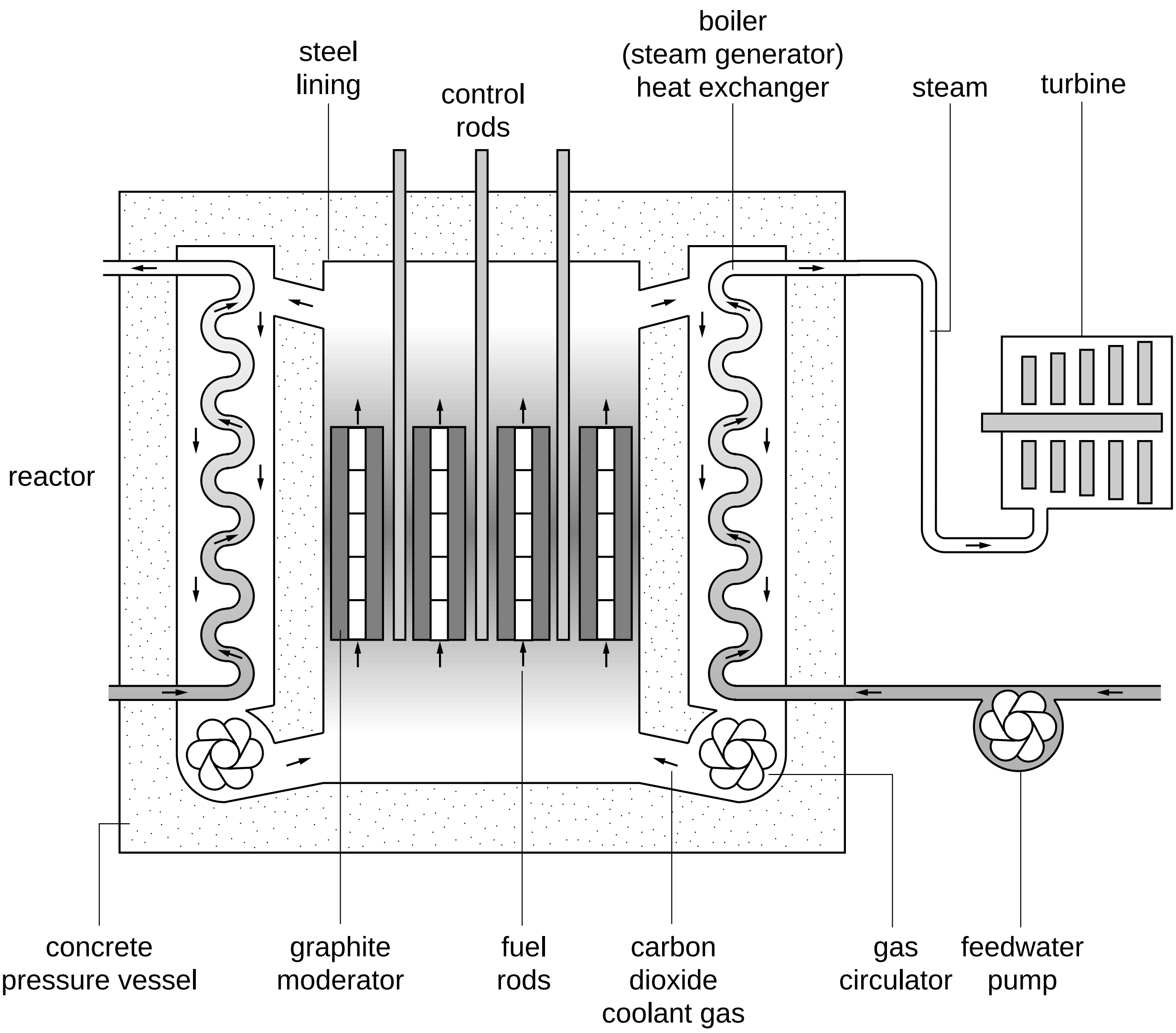

Fig. 1.9

A plan view of the arrangement inside the pressure vessel is shown in Fig. 1.10.

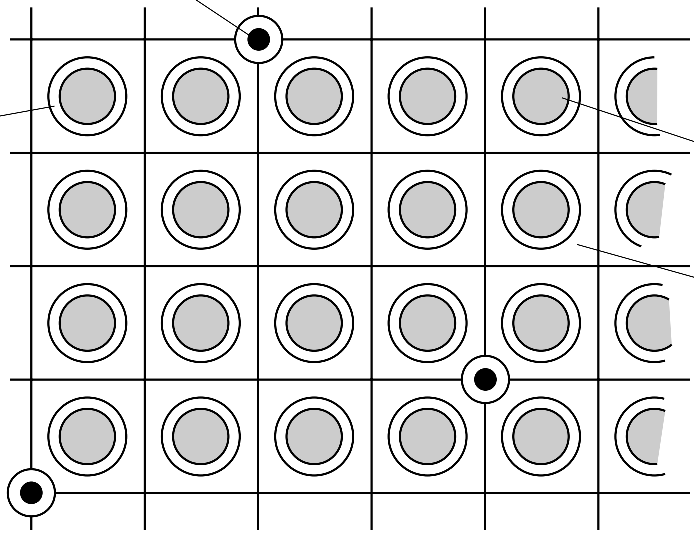

Fig. 1.10

The fuel rods, in their containers, are spaced out in grid formation and, in reactors of the Magnox type, are separated by blocks of carbon. The carbon is called the moderator and its function is to reduce the speed of the neutrons produced by the fission process. When a fission reaction occurs, most of the energy released is in the form of kinetic energy of the emitted neutrons. A high speed neutron, even if it goes very near another fissile nucleus, is not likely to be captured by the nucleus because it is moving so fast. If therefore the chain reaction is to be maintained, it is essential that the neutrons in the reactor are travelling slowly. It is the function of the carbon atoms in the moderator to get in the way of fast moving neutrons and hence to slow them down. Once they are travelling slowly, they are likely to diffuse, over a period of time, back into the uranium fuel rod. Another reason for slowing the neutrons down is that the uranium fuel contains atoms of two isotopes of uranium, the fissile $^{235}_{92}U$ and the non-fissile $^{238}_{92}U$. It so happens that slow neutrons are not absorbed very readily by $^{238}_{92}U$ nuclei so they can bounce around in the uranium fuel until they are absorbed by a $^{235}_{92}U$ nucleus. The last point to note about Fig. 1.10 is the presence of control rods. These are made of boron steel and can be inserted or withdrawn from the reactor in order to control the rate at which the reactor operates. Boron atoms absorb neutrons, so if the control rods are fully in the reactor there will not be enough neutrons available to sustain the chain reaction. When the rods are progressively lifted out of the reactor, a point is reached at which enough neutrons are present to keep the chain reaction going. The rate at which the reactor is producing power can therefore be controlled using these rods.

1 (i) Candidates should be able to calculate the potential energy stored in a lake, given its average depth, area and altitude.

1 (j) Candidates should be able to show an understanding of the main principles of a pumped water storage scheme.

When any hydro-electric scheme is planned, many factors need to be considered. If the scheme is a straightforward one then, apart from the social, economic and environmental considerations, the main consideration is the power output from the scheme. This will depend on such factors as the volume of water which can be stored in the lake, the rainfall over a period of time in the catchment area of the lake and the height of the lake above the power station. It is frequently the case with such schemes that the dam and the water it holds back is well above the power station to which it is connected. This is shown diagrammatically in Fig. 1.11.

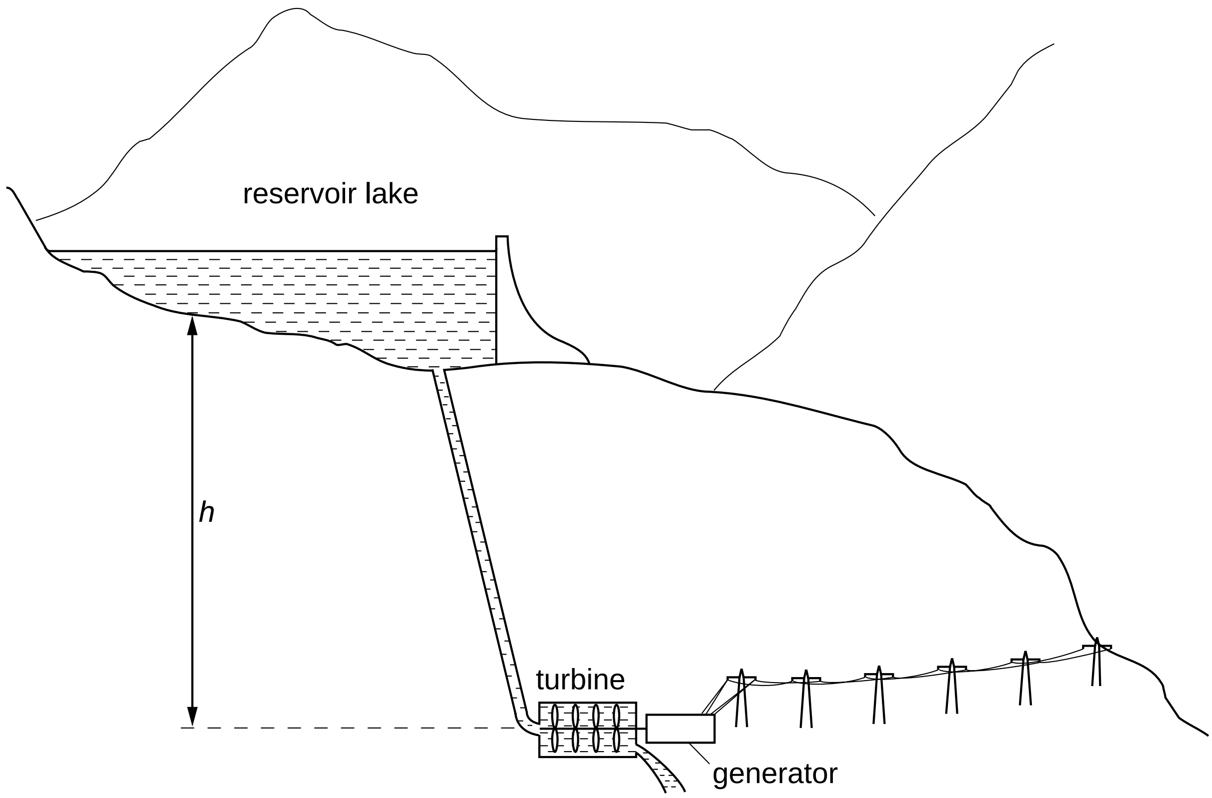

Fig. 1.11

In many Swiss valleys, the pipes leading from a high-level lake can be seen going into a power station although the lake itself is not visible from the valley floor. If the rainfall in the area is reasonably reliable, especially in winter when the demand for electricity is greatest, then the reservoir lake does not have to be too large. The purpose of the lake is to provide a flow of water to the power station at times when there is demand for electricity.

The total useful potential energy E_p stored by such a high-level lake is given by

$$E_p = Mgh,$$

where M is the mass of water stored and h is the height of the centre of gravity of the water above the power station, see Fig. 1.11. The value of M can be found from the product of the volume V of water stored and the density ρ of water. This gives

$$E_p = V\rho gh = Ad\rho gh,$$

where A is the surface area of the lake and d is its average depth.

In practice, it is more likely to be useful to know that the power P supplied by the falling water to the power station is given by $P = mgh$, where m is the mass of water supplied per unit time. Power stations such as the one illustrated usually have practical efficiencies of conversion to electrical power of around 80%.

In a country such as Britain, with a considerable number of nuclear power stations which need to be kept running for 24 hours each day if they are to achieve maximum efficiency, and with not much opportunity for large-scale hydro-electric schemes, it proves economical to use a pumped water storage hydro-electric scheme. This is similar to the arrangement shown in Fig. 1.11 but, additionally, there needs to be a lower level lake, or the sea, alongside the power station. After water has fallen from the higher level reservoir, it is stored in the lower level lake. At times of low electrical demand, for example during the night, spare electrical energy is used to pump water back from the lower level to the higher level so that during peak demand the following day the water can be re-used. This process can be repeated over and over again.

There is another advantage of either straightforward or pumped water storage hydro-electric schemes. Electrical demand fluctuates considerably during a day; a popular television programme finishing, for example, results in a large number of kettles being turned on and all of these require instant electrical power. A hydro-electric scheme can be made to respond very rapidly to extra demand. If the engineers at a hydro-electric power station are prepared for it, they can increase the output of the power station from a low idling rate to full power in less than ten seconds.

1 (k) *Candidates should be able to estimate the power available from a water wave of given dimensions.*

Any oscillating system has both kinetic energy and potential energy associated with it. The theory of simple harmonic motion shows that the total energy of the oscillation is proportional to the amplitude squared (Section 15). Travellers by sea are quite aware of this fact. If a storm develops so that the waves on the sea double in height, then the traveller will be four times more likely to be seasick! An approximate approach to finding the energy associated with a water wave, which actually gives a reasonably accurate result, considers a square wave as shown in Fig. 1.12. The wave of width w, amplitude A and wavelength λ has speed v.

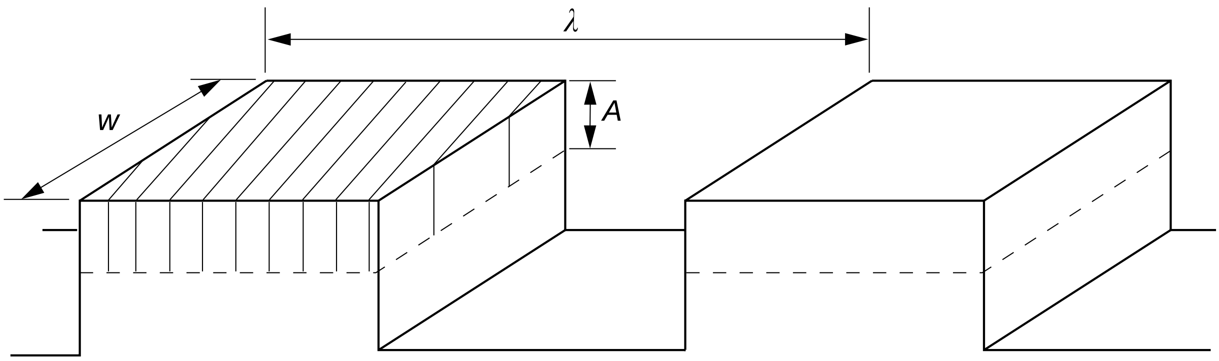

Fig. 1.12

The volume of the water shaded = $wA\lambda/2$.

The mass of the volume of water shown shaded = $wA\lambda\rho/2$, where ρ is the density of water.

This water has potential energy because it is above mean sea level. It would fall a distance A to make a calm sea. (It would fill up the space which is the next trough along.)

Hence, potential energy of the volume of water shown shaded = $\frac{1}{2}wA\lambda\rho gA$.

The number of waves passing any point per unit time = frequency = v/λ.

Therefore, the energy passing any point per unit time = $\frac{1}{2}wA\lambda\rho gAv/\lambda = \frac{1}{2}wA^2\rho gv$

and the power per unit width of wave = $\frac{1}{2}A^2\rho gv$.

It is instructive to put some sample numbers into this equation. Let a water wave have a speed of $8\,\mathrm{m\,s^{-1}}$ and a crest to trough height of 2 m; its amplitude is thus 1 m. With $g \approx 10\,\mathrm{m\,s^{-2}}$ and $\rho \approx 1000\,\mathrm{kg\,m^{-3}}$ then,

$$\text{power per unit width of wave} = \tfrac{1}{2} \times 1^2 \times 1000 \times 10 \times 8 = 40\,000\,\mathrm{W\,m^{-1}}.$$

If all of this energy could be transferred from a wave motion then it would be a very good source of power when the sea is rough. In practice, it has been found very difficult to devise a reliable system for making use of this power. The basic problem stems from the fact which was stated at the beginning of this section, namely that the energy associated with a wave is proportional to its amplitude squared. If a device is put into a wave to extract its energy, it can be designed for a particular wave amplitude. In the hostile environment of the sea, however, it must be strong enough to withstand the fiercest storms and this has resulted in great expense in manufacture.

1 (l) *Candidates should be able to show an understanding of how the potential energy of stored water is used to estimate the mean power output of a tidal barrage.*

A similar calculation to the one in section *1(k)* can be done for finding the maximum possible energy output for a tidal barrage in one high-low-high tidal cycle. Consider a barrage being shut at high water and retaining an area of water A. The tide then goes out to leave the situation as shown in Fig. 1.13, where the water at low tide is a height h below that at high tide.

The density of the water is ρ.

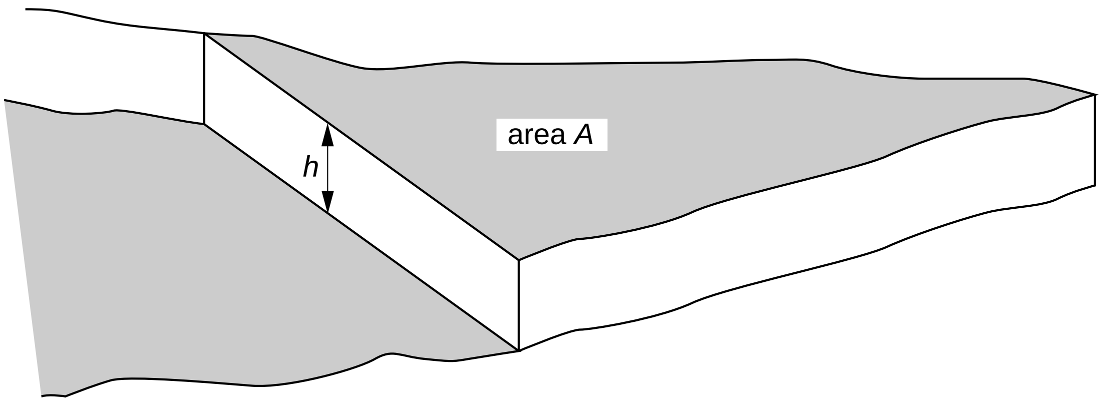

Fig. 1.13

The mass of water trapped $= hA\rho$ so

potential energy of the trapped water $= hA\rho g \times {}^1/_2 h = {}^1/_2 h^2 A\rho g$.

The River Rance in Brittany, France, has a tidal generation scheme which makes use of this energy and it has been suggested that the Mersey or the Severn Estuary could be the site for a tidal scheme in Britain. The figures again are interesting. On the Severn, the tidal range is about 10m and the area which might be enclosed is 300 km^2. This gives an amount of energy per tide as

$$E = {}^1/_2 \times 10^2 \times 300 \times 10^6 \times 1000 \times 10 = 1.5 \times 10^{14}\ \text{J}.$$

Since this energy is supplied over a period of time of about 12 hours, the maximum average power output is 3500 MW. This is a very large amount of power but, as is usual with these schemes, there are a number of disadvantages. The following is a list of some of them.

(i) The cost of such a barrage is very large.

(ii) The amount of environmental damage is unknown.

(iii) The assumption has been made here that all the water can be lost suddenly from behind the barrage when it is low tide. In practice, it would have to be released over a period of time and so would not lose as much potential energy. Note: it does not mean that the estuary above the barrage becomes tideless.

(iv) The time at which there is a supply of power is not able to be controlled. At some times, there would be maximum power available when there is least demand and, at other times, zero power available at times of peak demand.

(v) Silting up of the river would reduce the power output over a period of time. This has happened already with the Rance scheme.

(vi) The maximum practical power output, even with more sophisticated water control systems, will be well below the maximum theoretical output. It is thought that a scheme on the Severn might have an average power output of 2000 MW.

1 (m) *Candidates should be able to estimate the maximum power available from a wind generator.*

An example of a wind generator is shown in Fig. 1.14.

Fig. 1.14

The maximum power possible from a wind generator cannot be any greater than the kinetic energy of the air which passes through it per unit time. If all of this kinetic energy were extracted from the air, it would imply that the air stopped as it met the blades of the generator. This is an impractical situation. On the other hand, this kinetic energy does give an upper limit to the energy output possible. The expected actual power output would be a percentage of this, depending on the speed of the air after it has passed through the generator and on such factors as friction.

Consider a generator with blades of radius *r* facing directly into a wind of speed *v*, as illustrated in Fig. 1.15.

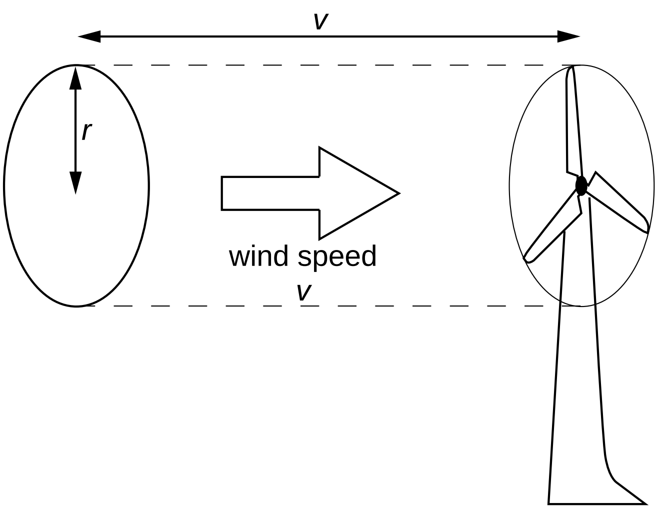

Fig. 1.15

The volume of air passing through the generator in unit time is the volume of the cylinder of length v, as shown in Fig. 1.15. This gives

volume of air $= \pi r^2 v$

and mass of air passing per unit time $= \pi r^2 v\rho$, where ρ is the density of air.

The kinetic energy of this mass $= {}^1\!/\!_2 mv^2$ $= {}^1\!/\!_2 \pi r^2 v\rho \times v^2$

$= {}^1\!/\!_2 \pi r^2 v^3 \rho$.

Since this is the kinetic energy of the wind passing into the generator in unit time, it is the power input to the generator. Wind generators of this type have been made with efficiencies of around 60% at certain speeds, but the presence of the cubed term in the expression deduced above implies that the power generated will be very dependent on the wind speed. If the wind speed is high, so that there is plenty of power available, then there are also considerable forces on the central axle where the blades are attached. This usually means that there needs to be a method for limiting the speed of rotation. This used to be done on old-fashioned windmills by opening a series of holes in the sails (the old name for the blades) and letting the air blow straight through.

1 (n) *Candidates should be able to comment on the difficulties and limitations associated with the following 'free' systems for producing power: geothermal including hot aquifers and geysers, biomass, methane generators from waste products.*

Most of the methods for producing 'free' electricity are still in the prototype stage. That is, some experimental work has been done on them and some theoretical calculations have been made to see whether or not the system is feasible in practice. If early results seem promising, then a large scale apparatus, the prototype, is constructed to see if a commercial scheme makes economic sense. As with many energy schemes, it is very difficult to make them viable economically while oil is so readily available. However, Brazil, which has a limited amount of hard currency to pay for oil imports, has legislated that motorists must use an ethanol-based fuel which can be manufactured from home-grown crops. This is called a biomass scheme because it uses energy directly from growing plants. Of course, the oldest source of energy known to man was a biomass scheme – that of burning wood on a fire.

Geothermal schemes use the energy of hot rocks in the Earth's crust. They involve sinking two pipes well down into the ground. Cold water is pumped down one of the pipes and hot water, resulting from contact with the hot rocks, rises from the other. This usually requires considerable capital expenditure and suffers from three fundamental problems.

(i) A considerable volume of the water pumped down is lost in cracks in the rock and does not re-surface.

(ii) After a while, the rock in a particular place cools down so the temperature of the water which does return to the surface gradually falls.

(iii) The temperature difference between the hot water and the cold water is not very large.

This makes any use of the hot water for power generation very inefficient (see section *3(f)*). Areas where this type of power generation is more effective are volcanic regions. This applies to, for example, parts of New Zealand where hot mud and boiling water issue from the Earth's surface. Engineers from New Zealand are, at present, using their experience in harnessing the energy to develop a system on St. Lucia in the West Indies. They hope to be able to harness power from the Soufrière volcano in the south of the island to produce enough electrical power to supply all of St. Lucia's electricity and even to be able to export some to the neighbouring island of St. Vincent.

The use of waste products to produce electricity is, on the face of it, very attractive. Two problems are solved with one solution. That is, how to get rid of the waste and how to supply enough energy.

Unfortunately, there is nothing like enough waste in the U.K. to supply all the electrical energy required so this method will never do more than contribute a small fraction of the total energy required. There is another problem with waste disposal schemes – no one wants them near their own homes. The 'nimby' effect is well known to anyone trying to design any power station. Put it somewhere else – Not In My Back Yard. Paris has endeavoured to overcome this problem with its waste disposal scheme at Saint Ouen. Here, a scheme to dispose of some of the waste from five million people was designed to be aesthetically pleasing. It incinerates over 600 000 tonnes of waste per year and supplies up to 6 MW to Electricité de France. Some 12 000 tonnes of scrap iron are recycled per year and air pollution is controlled by electrostatic precipitation and water-and-lime flue gas scrubbing. The plant has an energy efficiency of over 80% due to the city's district heating system. (See section *3(h)* on combined heat and power.)

A different form of waste is now being used to generate electrical energy. The water industry supplies water to our homes and also provides sewerage services. Thames Water uses a process of anaerobic digestion in which sewage sludge is enclosed in oxygen-free tanks. The bacteria present eat away the waste and emit a methane-rich biogas which can be burned to produce electricity. Thames Water is feeding enough electrical energy into the grid to supply the needs of about 25 000 households.

P2. Power Consumption

2 (a) *Candidates should be able to explain the daily and seasonal variations in the demand for electrical power.*

2 (b) *Candidates should be able to describe the complications which arise due to predictable and unpredictable variations in demand for electrical power.*

2 (c) *Candidates should be able to explain the benefits of a pumped water storage scheme.*

Electrical energy supplied through a grid network always has to be generated at the same instant as it is used. There is no way in which large quantities of electrical energy can be stored. This places considerable difficulties on the commercial suppliers of electrical energy because the demand for electrical energy is by no means constant and is often unpredictable. There are some obvious reasons why the demand for electrical energy varies. Increases in the demand for electrical energy take place

(i) in the winter, as much more electrical energy is used for heating, and, as fewer people are away on holiday, more industries are working at full capacity,

(ii) during the day as there is much more activity by day than by night,

(iii) just before festive occasions, when there is a great deal of activity and cooking,

(iv) on particularly cold days for heating, or hot days when air conditioning is being used,

(v) at the end of popular television programmes, when many people switch on a kettle.

Of course, several of these considerations may occur simultaneously, as, for example, on a particularly cold day just before Christmas in the U.K. It may be that a particular power station is only required for a few hours a year just to provide power at such a time. The demand in Great Britain just about reaches 50 000 MW at such times but, on other occasions, e.g. during the night on hot days at holiday times, the demand may drop as low as 13 000 MW. Needless to say, any maintenance which needs to be done at power stations, and which results in generators being shut down, is done during the summer months. Fig. 2.1 shows how the electrical demand in the U.K. varies on typical days during the summer and the winter.

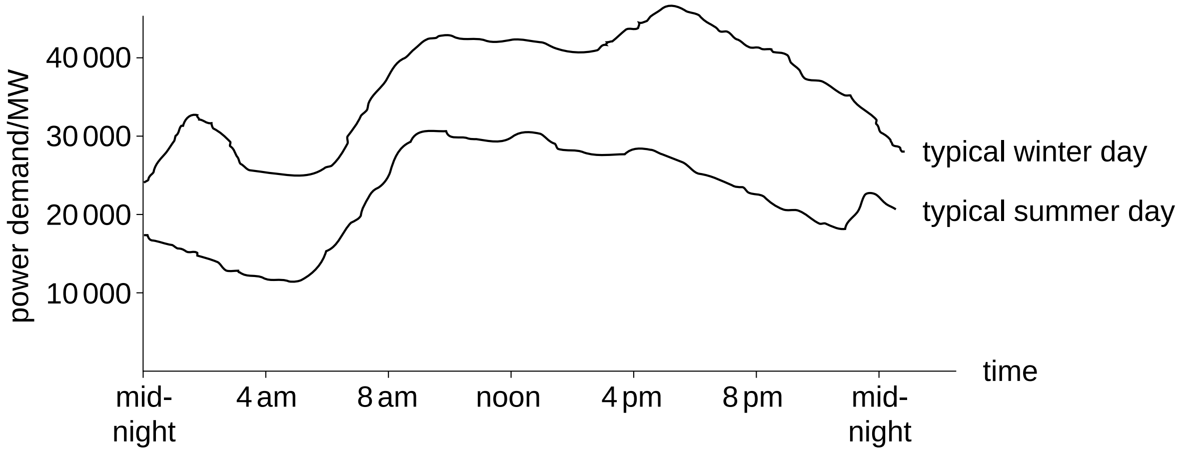

Fig. 2.1

Small peaks occur on the graphs just before midnight in the summer and just after midnight in the winter. The electricity distribution companies, in order to try to get people to spread their use of electrical energy over more of the day, charge some consumers on a lower tariff after 23.00 hours in the summer and after midnight in the winter. Many timers, on water heaters for example, are timed to switch on as soon as the lower tariff is being charged.

Controllers of the National Grid in the U.K. and the power stations try to anticipate changes in power demand. They keep a close eye on the pattern of consumption in previous days and the corresponding day in earlier years. They are in continual contact with weather forecasters and take careful note of the times at which television programmes end, together with their popularity ratings. This enables controllers to give advanced warning to the engineers running the power stations who can build up a reservoir of steam if they are given sufficient notice. The engineers at pumped storage schemes also need to be prepared for sudden changes in demand as they are the people who can respond most rapidly both to sudden extra demands and sudden drops in demand (see section *1(j)*). A dramatic news event can mean that people stop their usual activities. They might, for example, switch off their electric cookers, which use a large amount of power, and stay watching their television sets, which only use a small amount of electrical power.

If the controllers are taken by surprise by a sudden surge in demand, then the effect on the generators is to make them rotate more slowly. This reduces the frequency of the a.c. supply to a value below the 50 Hz to which it should be kept. Mains electric clocks would go more slowly: they are made to catch up during the night by increasing the frequency by a corresponding amount. A slow-running generator produces a lower voltage than it should. This would mean that the supply to houses would fall below the required 230 V r.m.s. A small fall in voltage does not make much difference but, at times of major difficulty, there is a danger to the system and to various appliances such as electric motors. It is occasionally necessary to shut down the whole electrical supply to a district or town.

2 (d) Candidates should be able to show an understanding that, although the efficiency for the conversion of electrical energy to internal energy for the consumer is 100%, the production of electrical energy is far less efficient.

If 2000 W of electrical power is supplied to the heating element of a kettle, then all of this power is converted into increasing the thermal energy of the kettle and its contents. This is one of the real advantages of energy in electrical form; it is easy to convert it, with high efficiency, into many other forms of energy. An electric motor, for example, can be 90% efficient in its conversion of electrical energy into kinetic energy. The remaining 10% of the energy heats up the motor, that is, it increases the internal energy of the motor. This can be a nuisance as an over-hot motor can result in the melting of the insulation on the wires in the motor. Unfortunately, although the conversion of electrical energy to other forms of energy can be very efficient, the production of electricity is nothing like as efficient. There are real problems in converting heat into work in any heat engine (see sections *3(f)* and *(g)*) and that is what a power station is doing. The heat from burning coal is being converted into work to drive the generator. Many power stations are only about 30% efficient and even the most modern ones only reach about 40% efficiency.

2 (e) *Candidates should be able to evaluate the overall efficiency, from production to consumer, of various domestic systems, e.g. cooking by gas or electricity.*

2 (f) *Candidates should be able to apply Sankey diagrams.*

A study of the energy changes which take place in any system usually leads to the conclusion that the changes are complex, involving not only useful energy but also energy losses. One means by which simple and complex situations may be represented is by the use of *Sankey diagrams*. Fig. 2.2(a) is a Sankey diagram representing the production and distribution of electrical energy by a generating station which is 35% efficient.

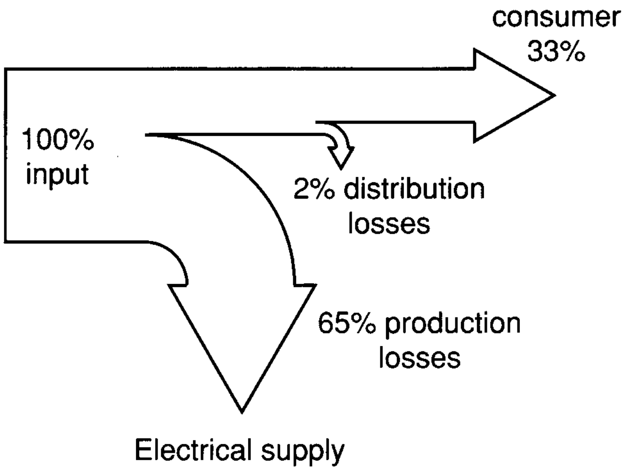

Fig. 2.2(a)

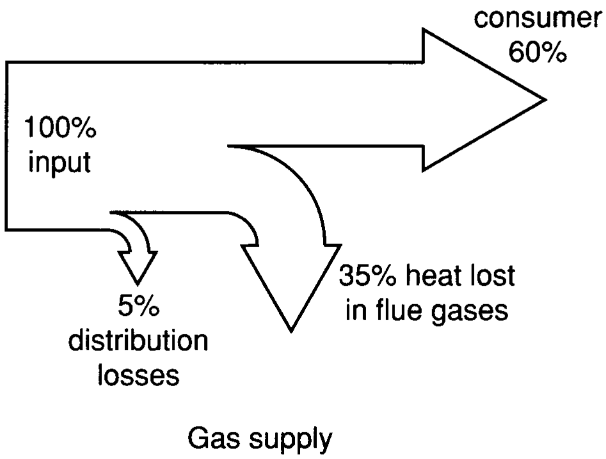

Fig. 2.2(b)

Each arrow represents a route along which some of the input energy has been transformed. The width of each arrow provides a visual representation of the proportion of the total energy in that particular route. The diagrams can be used to represent either energy distribution or power distribution. Thus, Fig. 2.2(a) indicates that 65% of the input energy is lost during the production of electrical energy and a further 2% of electrical energy is lost during distribution and so the consumer receives 33% of the input energy. Of course, the consumer has to pay for the full 100% cost of the input energy, so the cost of a kilowatt-hour supplied to the consumer's house is about 10 p. This contrasts with the Sankey diagram for a gas supply where, after some supply loss due to leaking pipe joints and the need to change gas pressure, 95% of the energy is supplied to the house. Losses of energy then take place when the gas is burned. Not all of the heat supplied by the gas to a cooker is transferred to the food. Much is lost by radiation and by convection currents. Fig. 2.2(b) shows an efficiency of 60% in transferring the energy to where it is wanted. Energy of one kilowatt-hour as supplied by gas costs about 3 p, but this would mean that you would have to buy 5 p worth of gas to get 1 kilowatt-hour of energy into the food.

Fig. 2.3 is a further Sankey diagram showing the way in which energy is utilised in a four-stroke petrol engine.

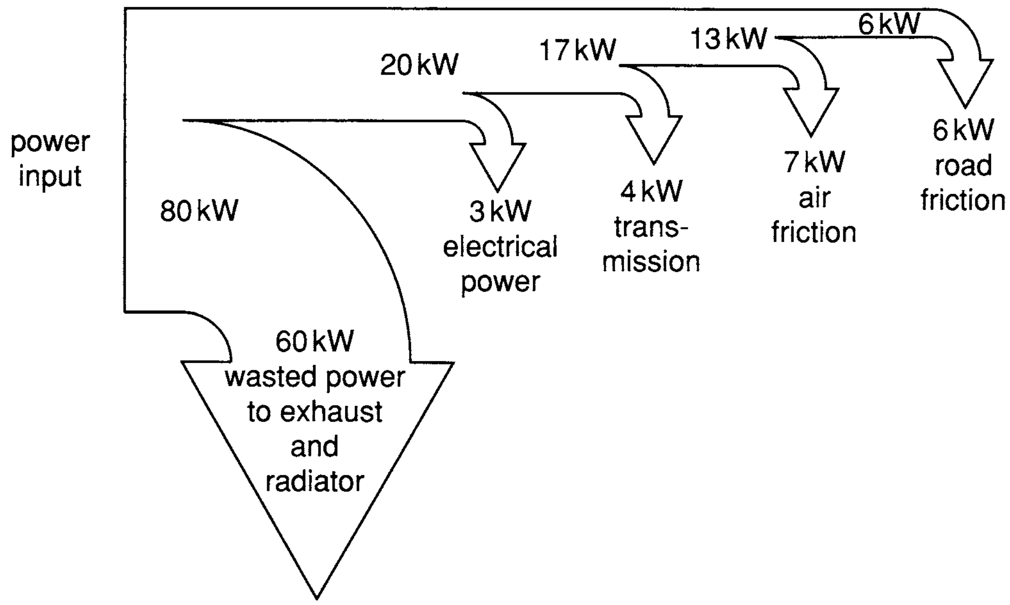

Fig. 2.3

2 (g) *Candidates should be able to predict the possible long-term effects on resources and on the environment of social changes such as increasing demand for housing, increasing affluence of third world countries and increasing use of air conditioning.*

The world-wide demand for energy is huge but it is by no means evenly distributed among the peoples of the world. On average, a person in the United States uses 30×10^{10} joules per year; a person in Great Britain uses 14×10^{10} joules per year whereas a person in India uses only 1×10^{10} joules per year. These figures are increasing all the time. The much increased use of air conditioning in the United States, for example, necessitates large increases in the supply of electricity. So too does the trend for fewer people to live in each house. It was quite common in the early part of this century for ten people to live in one quite small house. The heating costs per person were therefore very small, especially since there was usually only one fire in the house and that was used for both heating and cooking. No heat was provided in the bedrooms and there was no hot-water supply. Now there are a very large number of houses with only one person living in them and it is quite rare to find more than six people living in one house. As more houses are built, each with central heating or air conditioning, hot water, deep freeze, cooker, refrigerator, etc., more energy is needed per person. In the long term, this energy cannot be supplied by oil and gas, but the initial effect of increasing demand will be that the price of oil and gas will go up and only the wealthy nations will be able to afford the price. This will leave the third-world nations even worse off than they are already. The effect has already started.

Third-world countries have great difficulty exporting their produce and so they do not have enough hard currency available to pay for oil imports. With the exception of a few countries such as Nigeria, third-world countries generally do not have large reserves of their own oil. This is placing great strains on around 2.5 billion people living in rural areas in developing countries. There is a huge world-wide potential for photovoltaic cells but at present their use is limited: they are expensive and they too have to be imported by poorer countries. The

Director of Operations of the Intermediate Technology Development Group writes that 'Developing countries need greater and more secure access to energy if their economies are to grow and meet the aspirations of expanding populations. They have a desperate need to diversify energy resources and to make efficient use of what energy is available. They have diminishing access to wood and charcoal as the pressure on land increases.' He foresees thousands of small initiatives, using small-scale hydro-power stations, improved efficiency cooking stoves, windpumps and biomass schemes. These schemes, just as much as a few large-scale projects, can result in providing energy supplies for the world's poorer billions.

The ever-increasing demands for energy, its availability and rate of consumption have direct effects not only on the wealth of countries and the standard of living of their peoples, but also on the environment.

The recovery of fossil fuels, as with other mining operations, although bringing prosperity to companies and also to individual workers, does have a detrimental effect on the locality, e.g. open-cast mining. Although measures can be taken to reclaim sites, the area can never be returned to its original state. Accidents occur during mining and transportation (oil spillage from tankers, fractured gas pipelines) and these add to the burden on the environment. In some cases, the environment may take many years to recover, if at all.

The long-term effects of the use of fuels is not fully understood. It is recognised that pollution is inevitable and that this will affect the Earth and its atmosphere. However, the dynamics of mechanisms by which pollution is removed from, say, the atmosphere, are not fully realised or understood. Thus, there is much speculation as regards effects such as global warming and depletion of the ozone layers. Any fears for the future will increase as fuels are used at an ever-increasing rate.

P3. Heat Engines

A heat engine is a device which enables heat energy to be used to do work. The obvious example of such a device is a car engine. Petrol is supplied to the engine and burned inside it to produce heat. The useful output from the engine is the work done by the engine. Other examples of heat engines are power stations, trains and even people. The laws of thermodynamics can be applied to any system, and they produce some conclusions which are of crucial importance in the study of energy use.

A petrol engine works because a petrol-air mixture is burnt in a cylinder. The burning of this mixture forces a piston down as the volume occupied by the burning gases increases. It is the behaviour of the gases present which enables the engine to function. Because the behaviour of gases is well understood, it is possible to apply the laws of thermodynamics to the gas in the cylinder. In the analysis which follows, certain simplifying assumptions have been made. It is assumed that the gas under consideration is an ideal gas; that is, it obeys the gas laws precisely. In practice, this is not the case but, as in many fields of physics, the ideal situation is the simplest one to start with and then modifications can be made at a later stage to accommodate practical, rather than theoretical, data. It is also assumed that gases change from one state to another reversibly. This is a complex thermodynamic idea and involves moving from one stable state to another without passing through any unstable states. It would mean, for example, that in a car engine the gases do not swirl around giving any eddy currents. In practice they do. The overall effect of lack of reversibility is always to make changes less efficient in reality than the theoretical efficiencies obtained by assuming the gases behave reversibly.

3 (a) *Candidates should be able to distinguish between an isothermal change and an adiabatic change.*

3 (b) *Candidates should be able to illustrate isothermal and adiabatic changes on indicator diagrams.*

3 (c) *Candidates should be able to use the indicator diagram to determine the work done on or by a gas.*

When gas changes its volume without any change in temperature, it is said to undergo an *isothermal* change. In this case, Boyle's law applies; the pressure is inversely proportional to the volume. If this change is plotted on a graph of pressure against volume, the result is as shown in Fig. 3.1.

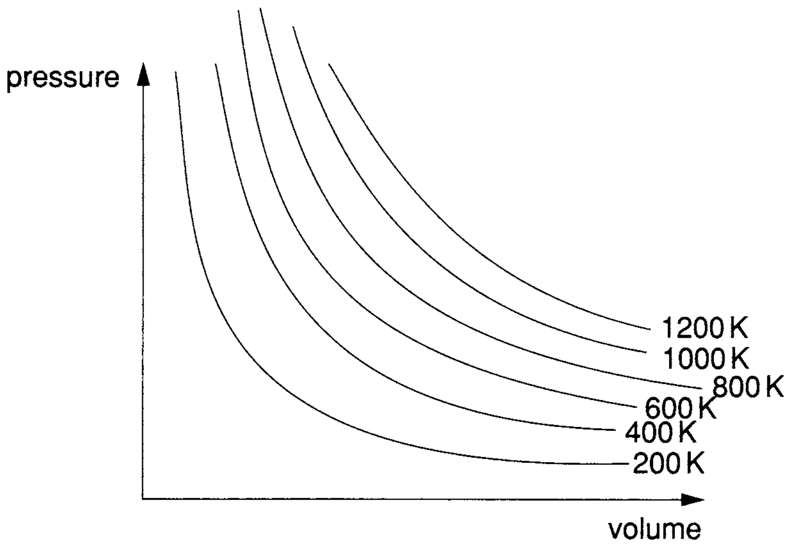

Fig. 3.1

Each line on the graph represents the variation of volume with pressure at a different constant temperature and is known as an *isotherm*. Such graphs are called *indicator diagrams*.

A gas can also change from one state to another by undergoing an *adiabatic* change. An adiabatic change in the state of a gas is when the volume of the gas changes without thermal energy being supplied or removed from it. (The volume would be reduced, for example, by having some work done on it.) The indicator diagram for an adiabatic compression is shown in Fig. 3.2.

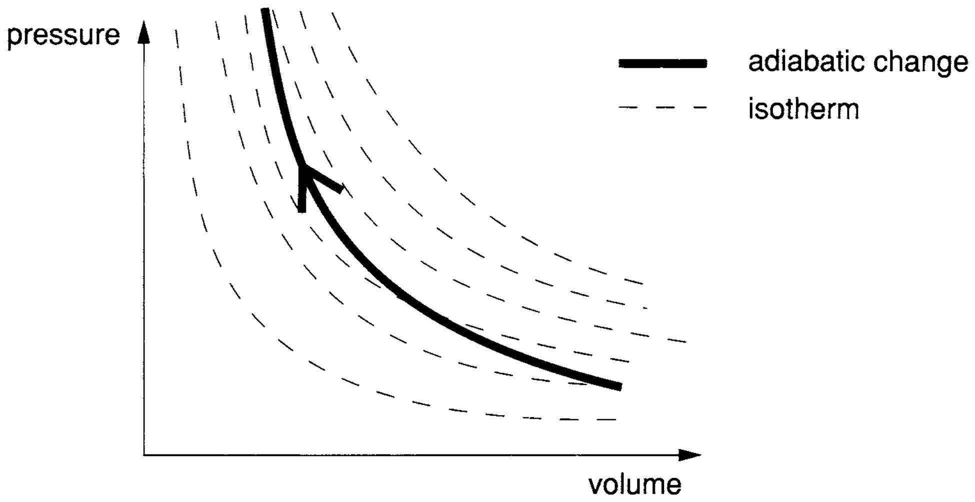

Fig. 3.2

On this diagram, a series of isotherms is shown dotted. The line for an adiabatic compression is always steeper than that for an isotherm, so an adiabatic compression always produces a rise in temperature. The temperature rises not because any heat is supplied to the gas but because work is done on it. (At a molecular level, this is because some of the molecules of the gas undergoing the compression are being hit by a piston moving towards them, thus increasing their speeds.)

One other feature of an indicator diagram which is useful is that the area beneath any line on the graph gives the work done on or by the gas. If a gas at a constant pressure of 100 000 Pa expands from a volume of 0.0001 m^3 to a volume of 0.0005 m^3 as a result of its temperature rising (see Fig. 3.3), then the work done by the gas on its surroundings is given by

work done by gas = pressure x increase in volume = $p\Delta V$

= 100 000 (0.0005 – 0.0001) J = 100 000 x 0.0004 J

= 40 J.

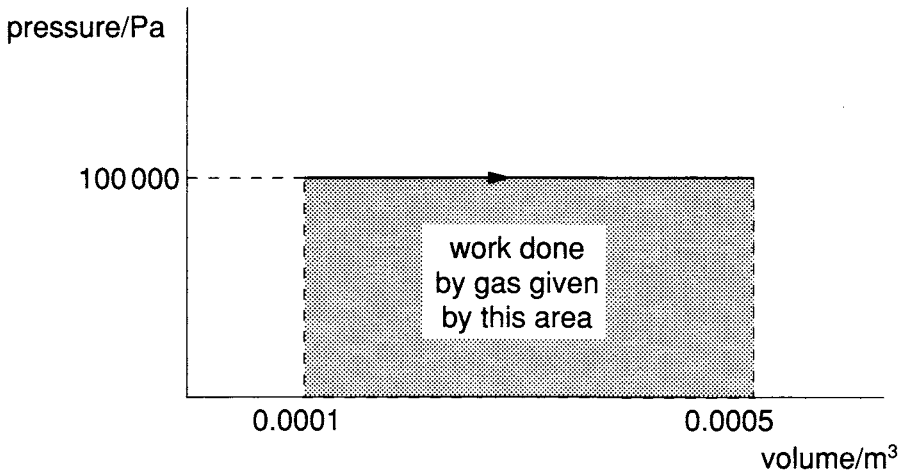

Fig. 3.3

It always pays to double-check the sign of any calculation such as this. Here, work is being done BY the gas and so a positive sign is required. If the calculation had been to find the work done ON the gas, then the answer would have been –40 J. This calculation is straightforward because the pressure remains constant. If the pressure does not remain constant then, theoretically, integration is needed to find the work done on the gas. However, the work done can always be found from the area beneath an accurately plotted graph. Note that a vertical line on an indicator diagram shows constant volume. This implies no movement and so zero work is done on or by the gas.

3 (d) *Candidates should be able to recall the cycle of a four-stroke petrol engine.*

3 (e) *Candidates should be able to illustrate and explain the cycle of a four-stroke petrol engine with the aid of an indicator diagram.*

Petrol engines are manufactured in a huge range of different types and sizes and modern engines are much more efficient than even those from 20 years ago. Fuel injection, additional valves, overhead camshafts, aluminium cylinder blocks, computer-controlled timing, turbo-charging and a whole range of other changes have not, however, altered the basic action of the engine which is illustrated by the four diagrams of Fig. 3.4.

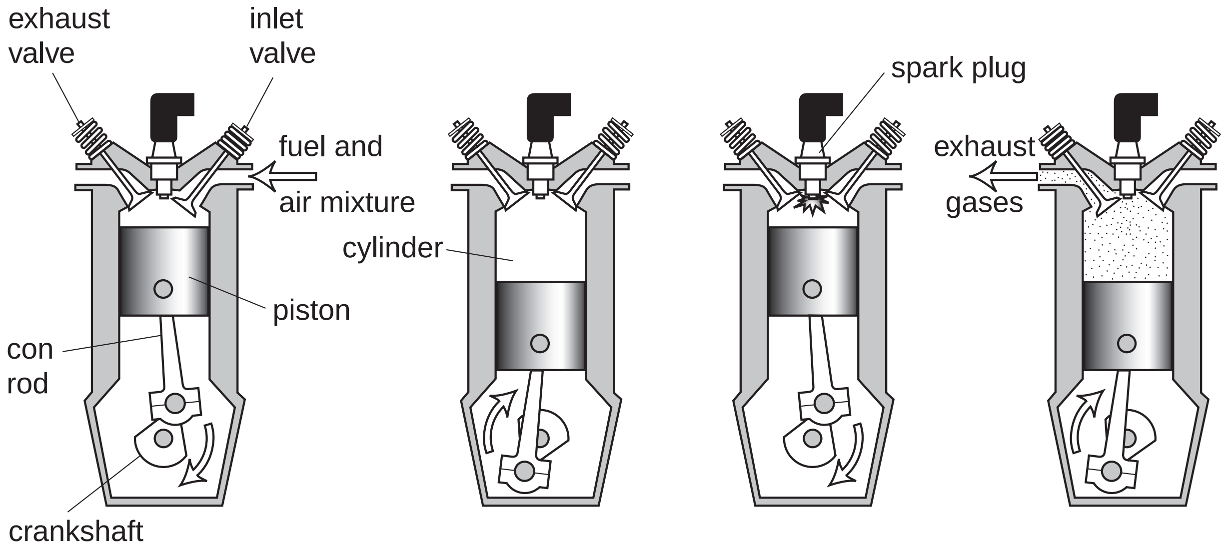

Fig. 3.4

The engine is characterised by four movements, or strokes, of the piston. The four strokes, two up and two down, are:

induction: The inlet valve is open and the exhaust valve closed. The piston moves down and a petrol vapour-air mixture is drawn into the cylinder.

compression: Both valves are closed. The piston moves up and the petrol vapour-air mixture is compressed adiabatically. The energy necessary to cause this compression comes from the flywheel and crankshaft to which the piston is attached by a connecting rod (con rod).

At the top of this stroke, the petrol is ignited by a spark at the sparking plug. This causes the power stroke.

power: Both valves remain closed. The piston moves down and an adiabatic expansion occurs. The energy provided by this stroke is supplied to the flywheel and hence to the road wheels.

exhaust: The exhaust valve opens and then the piston moves up. The burnt gases are pushed into the exhaust pipe and the engine is ready to start on the next induction stroke.

This cycle of operations can perhaps be memorised more easily by the terms *suck, squash, bang, blow*.

The cycle can be represented on an indicator diagram as shown in Fig. 3.5. It is more convenient to start drawing the indicator diagram at the start of the compression stroke because at that stage both of the valves of the engine are closed and so the mass of gas in the engine remains fixed.

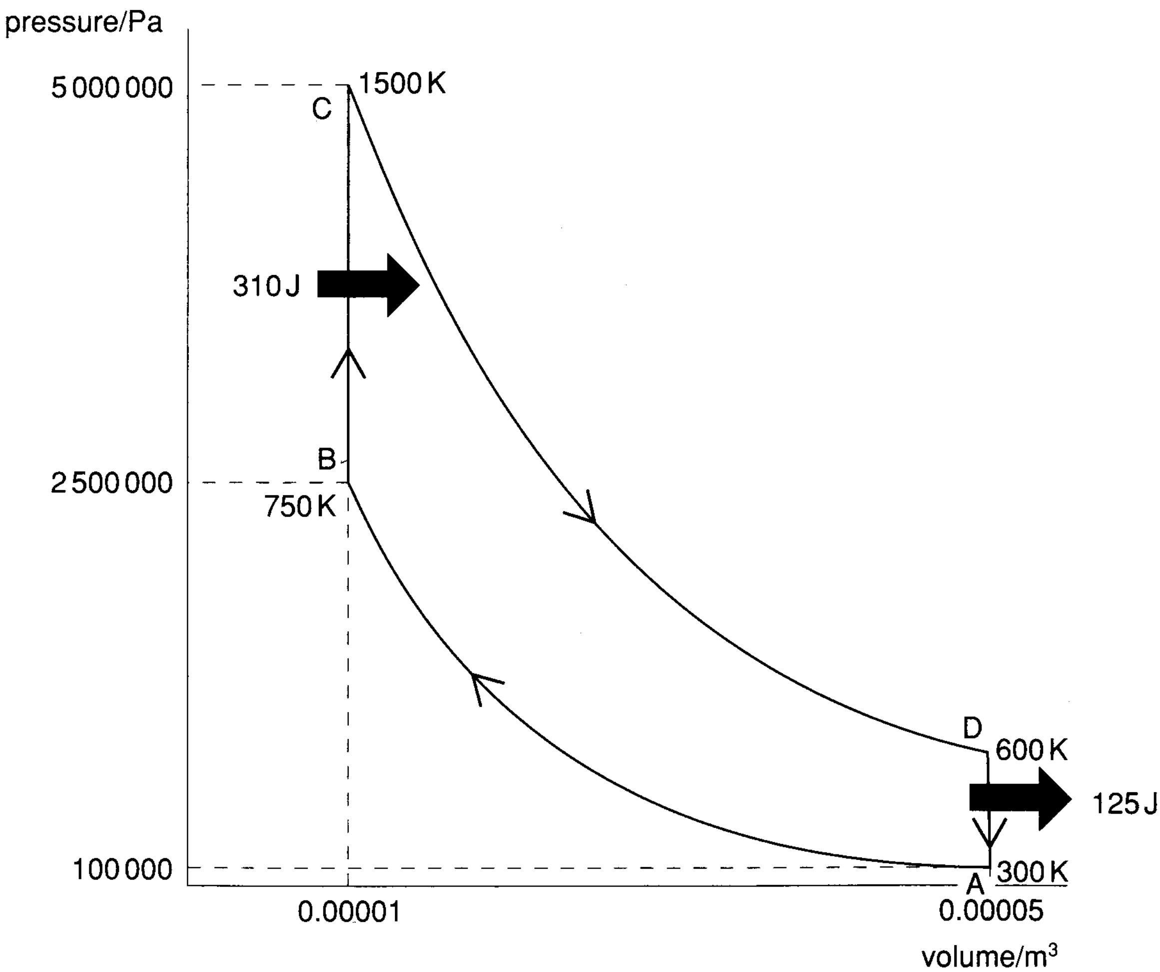

Fig. 3.5

A to B Adiabatic compression. Work is done on the gas.

B to C The burning petrol vapour causes an instantaneous rise in pressure and temperature. No work is done.

C to D The power stroke is an adiabatic expansion. Work is done by the gas or, to keep the terminology the same, the work done on the gas is negative.

D to A This, in practice, is a complicated sequence of operations including the exhaust and induction strokes. Here it is represented at its simplest, namely as a fall in temperature at constant volume. The purpose is to get back to the initial conditions so that the next cycle of operations can begin.

The figures on the indicator diagram, Fig. 3.5, have been obtained by using the gas laws and by use of the fact that the internal energy U of a gas at temperature T is given by

$$U = nc_vT,$$

where n is the number of moles of gas and c_v is the specific heat capacity at constant volume. The quantity of gas, in moles, in this example is 0.002, as can be checked by using the equation $pV = nRT$ at the point A on Fig. 3.5.

The maximum theoretical efficiency of the engine can be found if the first law of thermodynamics (Section 13) is applied to each part of the cycle. This has been done in the table below.

section of cycle	*heat supplied to gas* /J	+	*work done on gas* /J	=	*increase in internal energy* /J
A to B	0		185		185
B to C	310		0		310
C to D	0		–370		–370
D to A	–125		0		–125

In preparing this table, the 4 zeros can be put in first, 2 for the two adiabatic changes involving no heat supply and 2 for the sections where no work is done on the piston. Then the increase in internal energy can be inserted, as found from the equation given above ($c_v = 206\,\mathrm{J\,mol^{-1}\,K^{-1}}$). The result of these calculations shows that

(i) the heat supplied to the engine by burning the petrol vapour-air mixture is 310 J

(ii) the heat wasted in the exhaust gases is 125 J

(iii) the net work done BY the gas in the engine is given by 370 J – 185 J = 185 J

(Note that this figure must equal the difference between (i) and (ii).

The efficiency of the engine is therefore 185/310 = 0.60 or 60%.

3 (f) *Candidates should be able to show an appreciation that the second law of thermodynamics places an overall limit on the efficiency of a heat engine, and that this limit depends on the temperatures between which the engine is operating.*

3 (g) *Candidates should be able to recall and solve problems using the equation $E_{max} = (1 - T_L/T_H)$, where E_{max} is the maximum efficiency.*

Many assumptions have been made in making the deduction of the efficiency of the petrol engine above. If all the actual figures could be obtained, it would be found that the actual efficiency is less than that calculated. It is a fact that however this calculation is done, and for whatever engine it is done, it is never possible to convert all of a given amount of heat into work in an engine. This is a statement of the Second Law of Thermodynamics. It says that in trying to convert heat into work some heat is always wasted. It can be proved that the maximum possible efficiency, E_{max} is given by

$$E_{max} = 1 - \frac{T_L}{T_H} \quad ,$$

where T_L is the low temperature, i.e. the temperature of the surroundings of the engine, and T_H is the maximum temperature within the engine. T_L and T_H are thermodynamic temperatures. This equation implies that there is an overall limit on the efficiency of a heat engine and the limit depends on the temperatures between which the engine is operating. It should be noted that the efficiency can only be 1 (100%) if the temperature of the surroundings is zero, i.e. absolute zero. In practice, this is not possible so the only way that the theoretical maximum efficiency can be increased is by raising the higher temperature. This poses problems. To make an engine less massive, aluminium is often used in the manufacture of the engine block. This will melt if it is heated to too high a temperature. In most engines, the highest temperature reached by the burning gases is over the melting point of the engine itself. The engine has to be kept cool by circulating water through it. Another problem with using very high temperatures is that the pressure of the gases is very high and the engine needs to be strong to withstand the forces involved. In the 19th Century there were many awful accidents involving the exploding of steam engines because the steam in the engine had been superheated to improve the engine's efficiency.

3 (h) *Candidates should be able to deduce from the second law the conclusion that CHP (combined heat and power) schemes should be economical propositions.*

A power station is subject to the same laws which apply to all systems designed to convert thermal energy into work on the basis of continuous operation. A generating station supplying 500 MW of electrical power may have an operational efficiency of 40%. This can be shown on a Sankey diagram, Fig. 3.6.

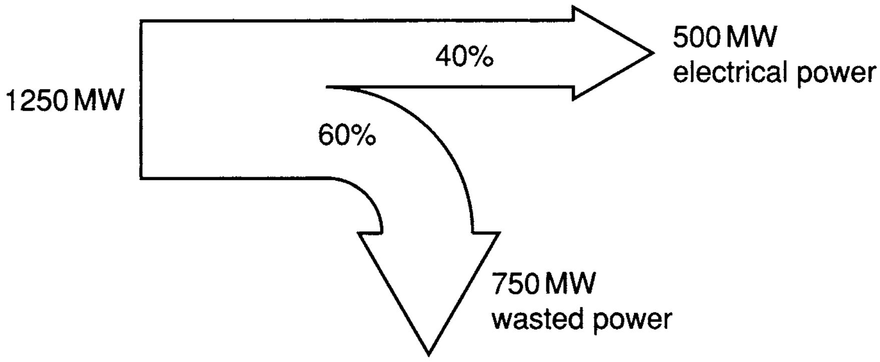

Fig. 3.6

The Sankey diagram shows that if 500 MW is 40% of the input, then the rate of thermal energy input must be 1250 MW. This means that no less than 750 MW of thermal power, at a low temperature, must be wasted by the generating station. Power stations all have a great deal of warm water to get rid of. They use cooling towers or rivers to remove this energy from the power station (see section *4(d)*). If there were people living conveniently near a power station, they could be supplied with warm water directly. Schemes which use this energy rather than wasting it are called *combined heat and power schemes* (CHP). Some are now in operation and the power generators are encouraged to make more use of them. If more CHP schemes are to be used, then power stations will need to be sited nearer to people's homes as it is impracticable to transport warm water through large distances around the country. By encouraging the use of CHP, the British government is expecting to reduce the emission of CO_2 into the atmosphere by a million tonnes per year.

P4. Pollution

4 (a) *Candidates should be able to show an appreciation that zero pollution is not possible.*

Whenever the subject of pollution occurs among politicians or industrialists or any other group of people, there is immediate agreement that pollution is wrong and should be prevented. Unfortunately, it is by no means easy to define pollution. Clearly, if someone deliberately releases a poisonous chemical into a river and kills thousands of fish, there is no doubt that he is polluting the river. What then, about the man who deliberately releases poisonous carbon monoxide into the atmosphere from the exhaust pipe of his car? This too is pollution, as is the emission of non-poisonous carbon dioxide from vehicles or even by people breathing it out. It is clearly a question of degree, but that in itself causes problems because someone, somewhere has to lay down standards as to what counts as pollution. A seaside resort cannot have a totally clean beach with totally sterile sea water. There will always be some bacteria present in the water. The amount can be monitored and if it is below a set standard the beach can be declared 'clean'. It can be put on a list of 'blue flag' bathing beaches. A beach at the next resort along the coast may have the same test done which gives similar results but with one particular type of bacterium slightly higher, taking it over the set standard. It does not get its 'blue flag' bathing beach, and next year, when the standards are altered, both of them may be deemed to be unsatisfactory. It is an insoluble problem. Pollution tends to be someone else's mess, not our own; it is for someone else to pay for the clear up, not us. What each of us can do, however, is to be responsible and vigilant and to demand high standards and to be prepared to pay the extra costs which high standards require.

What is clear is that it is not possible to avoid all pollution. Some pollution is inevitable, and it is for society to decide what levels of pollution are acceptable both as regards the risk to the health of individuals and also the appearance of our surroundings. A great deal has already been done to reduce pollution. The "Black Country" in England was black in the 19th Century because of the huge amount of pollution being emitted from factory chimneys. Views of the Potteries right up to the middle of the 20th Century are full of smoke stacks belching forth vast quantities of gases and particles. Curtains, clothing and washing were never clean for longer than a few days. All this has now changed radically. The chimneys themselves have been pulled down; towns and cities are now much cleaner and thick choking smogs, such as the one in London in 1952 during which there were 2000 deaths over and above those expected for the time of year, are a thing of the past. The Clean Air Act of 1956 resulted in far less coal being used for heating houses and consequently much more winter sunshine.

4 (b) *Candidates should be able to distinguish the burning of fossil fuels from nuclear and hydro-electric power schemes in terms of the release of carbon dioxide into the atmosphere.*

4 (c) *Candidates should be able to show an understanding why carbon dioxide levels in the atmosphere are not rising rapidly.*

A greenhouse operates on the principle that glass is transparent to the infra-red radiation from the Sun. Thus, fittings and plants within the greenhouse are heated. Infra-red radiation is also emitted by objects within the greenhouse, but this radiation has a longer wavelength than that from the Sun because the Sun's temperature is much higher than that in the greenhouse. The longer wavelength radiation is not transmitted through the glass. Consequently, energy is trapped inside the greenhouse, giving rise to a heating effect.

Certain gases show similar transmission and absorption properties to those of glass. As a result, if these gases are present in sufficiently large quantities in the Earth's atmosphere, the temperature near to the Earth's surface will rise. This effect is known as the *greenhouse effect*.

The United Nations Framework Convention on Climate Change was signed by over 150 countries at the Earth Summit in Rio de Janeiro in 1992. Its intention is to stabilise greenhouse gas concentrations in the atmosphere. The main greenhouse gas is carbon dioxide which is produced by the burning of all conventional fuels. A typical chemical equation is that for the burning of methane, which is the main gas present in natural gas.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{energy}$$

The water produced condenses but the carbon dioxide adds to the carbon dioxide which is always present in the atmosphere. Carbon dioxide is essential in the atmosphere for plant growth. Plants produce their own food by the process of photosynthesis. The following equation shows the production of a carbohydrate by this method.

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

The equation shows that, apart from the carbohydrate, oxygen is also produced. Plants therefore use carbon dioxide from the atmosphere in order to grow. Indeed, some nurserymen deliberately raise the level of carbon dioxide in their greenhouses in order to promote rapid growth.

The aim of the Earth Summit is to establish a dynamic equilibrium between these two processes; that is, to make the rate at which carbon dioxide is produced equal to the rate at which it is absorbed by plants. At present, this equilibrium is not established because so much fossil-fuel burning takes place. Governments throughout the world were committed by their signing of the Convention to take measures to limit the emission of carbon dioxide and other greenhouse gases to 1990 levels by the year 2000. This is only the start of the long-term aim of dynamic equilibrium. In order to keep the emission of carbon dioxide down, the British government is using a variety of different means. These include

(i) reducing the demand for energy by insisting on higher standards of insulation in, for example, houses. If a thicker blanket of insulation is used in the walls and roofs of new houses, central heating will not need to be switched on for so long.

(ii) using nuclear power, which does not use fossil fuel and does not produce greenhouse gases,

(iii) using renewable resources such as hydro-electric power, wind power, solar power,

(iv) using more efficient electrical generating plant. Gas-fired combined cycle plant has emissions of carbon dioxide per unit of electrical energy generated only about half that of conventional coal-burning plant.

(v) increasing the tax on fuel,

(vi) encouraging the use of combined heat and power (CHP). To some extent, this has been done by making a change in the law. When the electricity industry was originally nationalised, its purpose was stated to be the efficient production and distribution of electrical power. It did not have authority or direction to sell hot water. By altering the code of practice under which generation and distribution are carried out, the electricity companies can now improve their profitability by selling energy in any form they wish.

4 (d) Candidates should be able to show an understanding of other forms of pollution, such as thermal pollution of the atmosphere, noise pollution, pollution of rivers.

Pollution comes in many different forms and any comment on pollution will inevitably omit some. Not all pollution is artificial; some of the worst and greatest forms of pollution are caused by natural phenomena. For example, a volcano in the Philippines and another in Papua New Guinea have scattered ash and rocks in vast quantities over large areas of land and sea within the last few years, destroying a great deal of vegetation and animal life.

Some pollution is undoubtedly beneficial, at least to some people. The simple act of building a house in a pleasant area of the countryside can be said to be polluting the countryside, especially by those people who live nearby, but the people who enjoy living in the house do not think of it as pollution, and neither did their neighbours think of their own houses as pollution when they were built some time earlier. Different types of pollution annoy different people. Any form of river pollution is always abhorred by everyone, yet it does still take place. Sewage plants do not work with 100% efficiency all of the time. When some people have an obnoxious liquid which they want to get rid of, they are all too ready to throw it in a river rather than pay someone to treat it properly. Noise pollution is a rather more contentious issue. When a club has a party, the noise generated adds to the convivial atmosphere. But the noise is just annoying to people who live near the club and for whom the party might be the third they have had to listen to in the last three days. Because of these problems, noise levels and duration have to be monitored and controlled.

Thermal pollution of the atmosphere or of rivers or of the sea will only be significant if a very large industrial plant, such as a power station, is releasing large quantities of thermal energy into the environment. This can contribute to global warming or to changes in the micro-climate of a particular locality. Some types of pollution are controlled by law; some are not. In the UK, all District Councils have officers responsible for limiting pollution, and County Councils have responsibility for the safe disposal of waste. The recently established Inspectorate of Pollution has national responsibility for ensuring that the laws on pollution are obeyed.

As a first step towards sensible handling of pollution, it is necessary to have reliable data about how the situation is changing. Monitoring pollution levels needs to be done systematically over a long period of time because, in general, the amount of pollution does not change very rapidly. Modern instrumentation for monitoring is very sensitive, and some monitoring is being done from geostationary satellites. There is a danger that too much data will be obtained and that significant quantities of one pollutant will be ignored while too much attention will be given to insignificant quantities of another pollutant. Deciding on priorities demands skill and judgment.

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