7 Read the passage below and answer the questions that follow.

Most sources of energy originate directly or indirectly from the Sun, including fossil fuels, conventional hydroelectric, wind, biofuels, wave power and solar. Unlike these, tidal power is the only source of energy which is drawn directly from the relative motions of the Earth-Moon system. The gravitational forces produced by the Moon and the Sun, in combination with the Earth's rotation, are responsible for the generation of the tides. Periodic changes of water levels and associated tidal currents are due to the gravitational attraction by the Sun and Moon. Tidal power is practically inexhaustible and classified as a renewable energy source. A tidal energy generator uses this phenomenon to generate energy.

Currently, although the technology required to harness tidal energy is well established, tidal power is expensive, and there is only one major tidal generating station in operation. This is the La Rance on the northern coast of France. It has 24 turbines rated at 10 MW each with a total capacity of 240 MW.

Tidal energy is like most other forms of renewable energy in that it cannot be relied upon 100% of the time, so the value quoted above will never be generated in a year. A value of capacity factor C_F is used to estimate the percentage of the maximum that will actually be generated in a year.

$$C_F = \frac{\text{electrical energy actually generated}}{\text{theoretical maximum electrical energy output from generators}}$$

The high and low tides that generate tidal energy are caused by the Moon. Consider the gravitational force exerted on the Earth by the Moon. The tidal force is the small difference between the actual force exerted on a piece of Earth matter at the Earth's surface and the force exerted on the same piece if it were placed at the Earth's centre.

We can write down an equation for the tidal force exerted by the Moon (of mass M at a distance r from *Earth*) on a body (of mass m) placed along the line joining the Earth (of radius R) to the Moon as shown in Fig. 7.1.

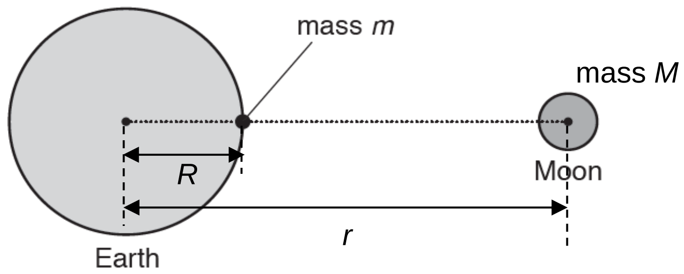

Fig. 7.1 (not to scale)

Assuming R is much smaller than r, the Moon's tidal force F_M directed away from the Earth's centre has magnitude

$$F_M = \frac{2GMmR}{r^3}$$

The tidal force due to the Moon causes the Earth—and its water—to bulge out on the side closest to the Moon and the side farthest from the Moon. These bulges of water are high tides.

The Sun causes tides just like the Moon does, although they are somewhat smaller. When the Earth, Moon, and Sun line up—which happens at times of full moon or new moon—the lunar and solar tides reinforce each other, leading to more extreme tides, called spring tides. When lunar and solar tides act against each other, the result is unusually small tides, called neap tides. The spring and neap tides are illustrated in Fig. 7.2.

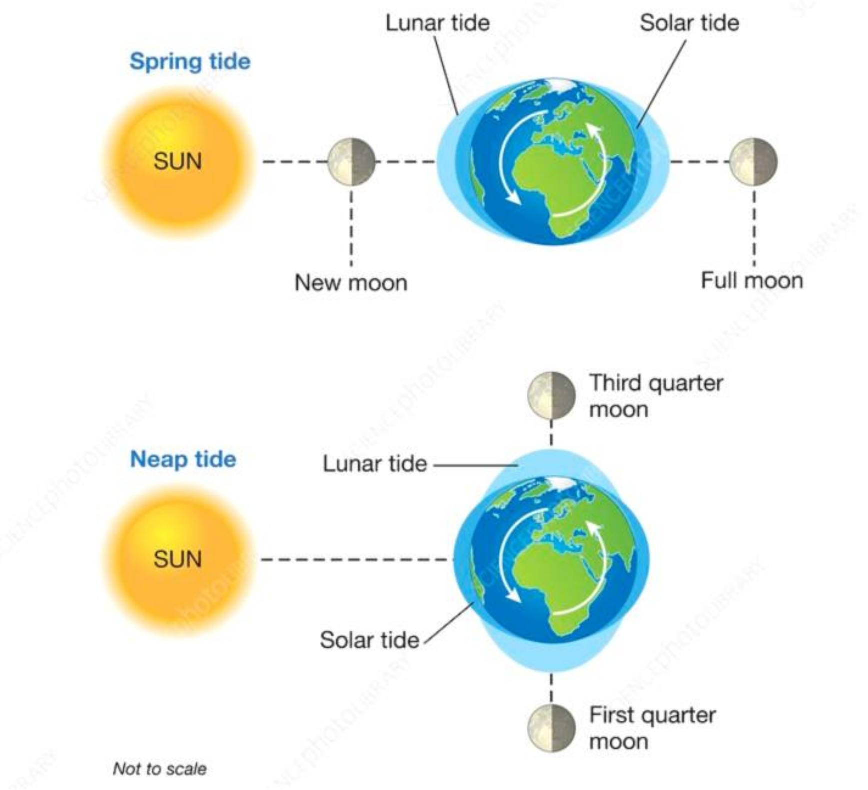

Fig. 7.2

(a) **(i)** Suggest the process in the Sun responsible for providing the energy for fossil fuels, wind energy, biofuels, wave power and solar energy.

....

.... [1]

(ii) The energy source for the La Rance power station is not the Sun. Describe two origins of the energy source for the La Rance power station.

1...

....

2 ....

....

[2]

(b) On a particular day, this power station is operating and supplying energy to the French national grid.

(i) State the useful energy change that occurs during this time.

.... [1]

(ii) Suggest two mechanisms by which energy is wasted as thermal energy during the operation of the power station.

1. ………………………………………………………………………………………………

....

2. ....

.... [2]

(c) The variation in sea level is measured at the La Rance. Fig. 7.3 shows how sea level varies with time on a specific day after the largest high tide of the year.

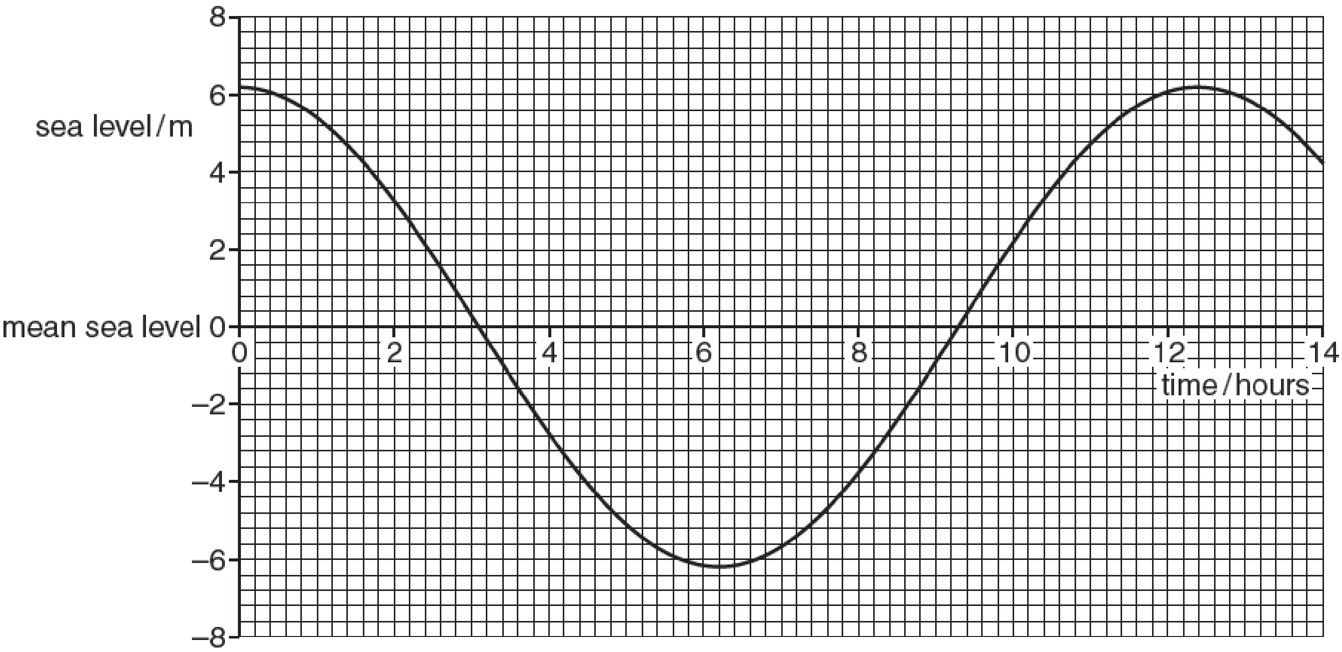

Fig. 7.3

At high tide, sluice gates are closed and water is trapped in the estuary.

At the next low tide, the gates are opened and seawater of density 1.03×10^3 kg m^{-3} flows through the generators at a rate of 2100 m^3 s^{-1}.

(i) Calculate the rate at which the water loses gravitational potential energy.

rate = ... J s^{-1} [2]

(ii) The power station operates with an efficiency of 90.5%. Calculate the output power of the power station.

output power .... MW [1]

(iii) The output power is supplied to the national grid at 225 kV. Calculate the current supplied.

current = ... A [2]

(d) At the La Rance, the actual annual output of energy is 5.4 x 10^8 kWh.

(i) Calculate the capacity factor C_F of the La Rance power station.

capacity factor = ………………… [3]

(ii) Suggest one reason why it is not possible for the capacity factor of a tidal power station to be equal to 1.00.

....

.... [1]

(e) **(i)** The table gives data for the Earth, Moon and Sun.

radius of Moon's orbit around the Earth	3.84×10^8 m
radius of Earth	6.38×10^6 m
radius of Earth's orbit around the Sun	1.50×10^{11} m
mass of Sun	1.99×10^{30} kg
mass of Earth	5.97×10^{24} kg
mass of Moon	7.35×10^{22} kg

1. Calculate the magnitude of the Moon's tidal force F_M on 1.00 kg of seawater, at the position shown in Fig. 7.1.

F_M = ... N [2]

2. When the Earth, Moon and Sun are in a straight line the Sun's tidal force on 1.00 kg of seawater in Fig. 7.1 is F_S.

Calculate the ratio $\frac{F_M}{F_S}$ and comment on the significance of your answer.

$\frac{F_M}{F_S}$ = ...

……..

....

....

.... [3]

(ii) State in terms of tidal forces, when and how spring tides are formed.

……..

....

....

.... [2]

[End of Paper]