
PHYSICS (PRINCIPAL)

9792/02

Paper 2 Written Paper

May/June 2016

PRE-RELEASED MATERIAL



The question in Section 2 of Paper 2 will relate to the subject matter in these extracts. You should read through this booklet before the examination.

The extracts on the following pages are taken from a variety of sources.

Cambridge International Examinations does not necessarily endorse the reasoning expressed by the original authors, some of whom may use unconventional Physics terminology and non-SI units.

You are also encouraged to read around the topic, and to consider the issues raised, so that you can draw on all your knowledge of Physics when answering the questions.

You will be provided with a copy of this booklet in the examination.

The syllabus is approved for use in England, Wales and Northern Ireland as a Cambridge International Level 3 Pre-U Certificate.

This document consists of **10** printed pages and **2** blank pages.

Extract 1: Tidal barrages

Tidal barrages work like a hydroelectric scheme, but the dam is much bigger. A huge dam, or a barrage, is built across a river estuary. When the tide goes in and out, the water flows through tunnels in the dam.

Fig. E1.1 shows that, as the tide comes in, the dam allows the seawater to pass into a holding basin. As soon as the tide is about to go out, the dam is closed. The water held back in this way will be used to feed the turbines at low (ebb) tide, as shown in Fig. E1.2.

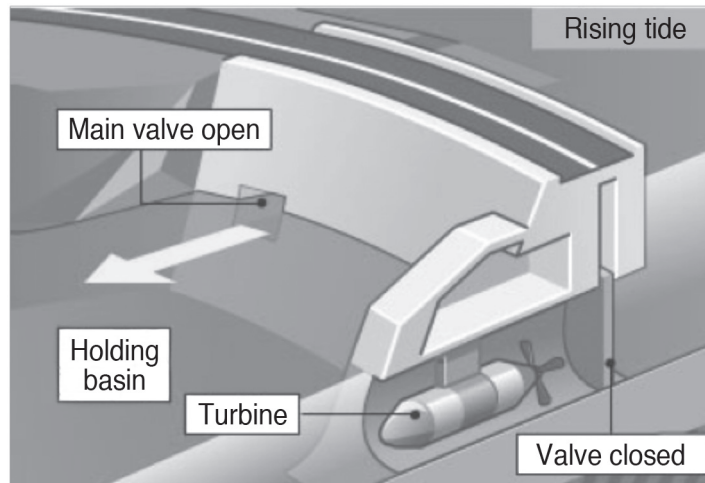


Fig. E1.1

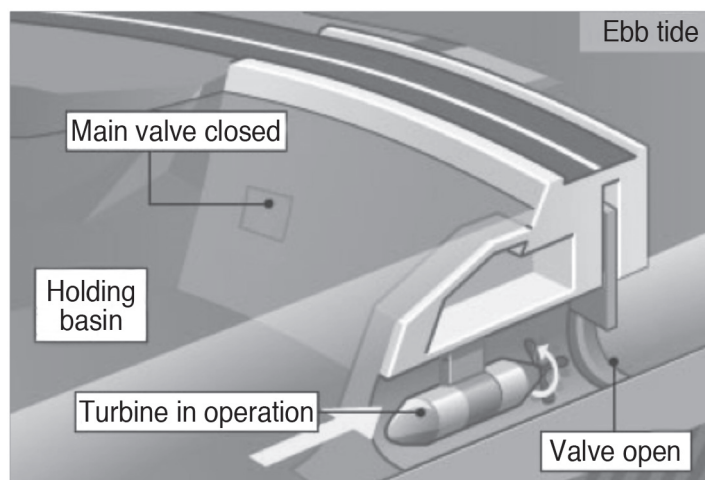


Fig. E1.2

The ebb and flow of the tides can be used to turn a turbine, or it can be used to push air through a pipe, which then turns a turbine.

There are a number of benefits of a tidal barrage, including protecting a large stretch of coastline against damage from high storm tides, and providing a ready-made road bridge. However, the drastic changes to the currents in the estuary could have huge effects on the ecosystem, and large numbers of birds that feed on the mud flats in the estuary when the tide goes out would have nowhere to feed.

A major drawback of tidal power stations is that they can only generate for about 10 hours each day. However, tides are totally predictable, so we can plan to have other power stations generating at those times when the tidal station is out of action.

Extract 2: The source of tidal energy

Tidal power is the only source of energy which derives directly from the relative motions of the Earth-Moon system, and to a lesser extent from the Earth-Sun 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. Most other sources of energy originate directly or indirectly from the Sun, including fossil fuels, conventional hydroelectric, wind, biofuels, wave power and solar. Nuclear energy is derived using radioactive material from the Earth; geothermal power uses the heat of magma below the Earth's crust, which comes from radioactive decay.

Tidal energy is generated by the relative motion of the Earth, the Sun and the Moon, which interact via gravitational forces. Periodic changes of water levels and associated tidal currents are due to the gravitational attraction by the Sun and Moon. The magnitude of the tide at a location is the result of the changing positions of the Moon and the Sun relative to the Earth, the effects of the Earth's rotation and the local shape of the sea floor and coastlines. Tidal power is practically inexhaustible and classified as a renewable energy source. A tidal energy generator uses this phenomenon to generate energy. The stronger the tide in water level height, the greater the potential for tidal energy generation.

The natural tidal movement causes a continuous loss of energy in the Earth-Moon system due to friction caused by the pumping of water through the natural restrictions around coastlines and due to viscous forces dissipating energy at the seabed, and in turbulence. This loss of energy has caused the rotation of the Earth about its own axis to slow in the 4.5 billion years since formation. During the last 620 million years the period of rotation has increased from an estimated 21.9 hours to the 24 hours we see now. In this period the Earth has lost 17% of its rotational energy.

As the rotation of the Earth slows, its angular momentum decreases. Since the angular momentum of the Earth-Moon system must be conserved, the distance between the Earth and the Moon increases. This actually causes an increase in gravitational potential energy, but this is partially offset by the decrease in kinetic energy of the Moon. Tidal power may take additional energy from the system, increasing the rate of slowing over the next millions of years.

Adapted from: <http://diaxiomtechnologies.com/tidal>

Extract 3: Output from the La Rance tidal barrage

The construction of this barrage began in 1960. The system used consists of a dam 330m long, and a 22km² basin with a tidal range of over 8m. It incorporates a lock to allow passage for small craft. During construction, two temporary dams were built on either side of the barrage to ensure that it would be dry. This was for safety and convenience. The work was completed in 1967 when twenty-four, 5.4m diameter bulb turbines, rated at 10MW, were connected to the 225kV French transmission network. Fig. E3.1 shows the barrage.

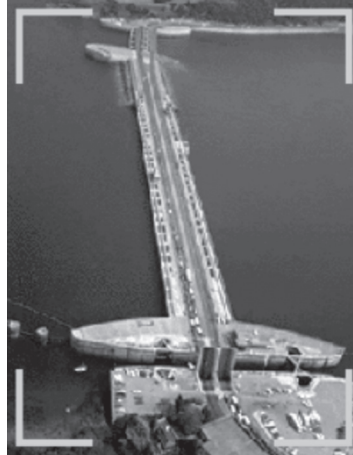


Fig. E3.1

This barrage uses bulb turbines, which were developed by Électricité de France. This type of turbine has been used in mainland Europe in dams on the Rhine and Rhone rivers.

The 24 turbines are rated at 10 MW, and therefore have a total capacity of 240 MW.

Theoretical maximum electrical energy output from generators per annum
 = 240 000 (kW) × 365 × 24 (hours) = 2 102 400 000 kWh

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.

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

Adapted from: http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/tidal1.htm

Extract 4: What is tidal energy?

Tidal energy is one of the oldest forms of energy used by humans. Indeed, tide mills, in use on the Spanish, French and British coasts, date back to the year 787. Tide mills consisted of a storage pond filled by the incoming (flood) tide through a sluice and emptied during the outgoing (ebb) tide through a water-wheel. The tides turned water-wheels, producing mechanical power to mill grain. We even have one remaining in New York – which worked well into the 20th century.

Tidal power is non-polluting, reliable and predictable. Tidal barrages, undersea tidal turbines – like wind turbines, but driven by the sea – and a variety of machines harnessing undersea currents are under development. Unlike wind and waves, tidal currents are entirely predictable.

Tidal energy can be exploited in two ways:

- by building semi-permeable barrages across estuaries with a high tidal range
- by harnessing offshore tidal streams

Barrages allow tidal waters to fill an estuary via sluices and to empty through turbines. Tidal streams can be harnessed using offshore underwater devices similar to wind turbines.

Most modern tidal concepts employ a dam approach with hydraulic turbines. A drawback of tidal power is its low capacity factor, and it also misses peak demand times because of the 12.5 hour cycle of the tides.

The 7.5–9.0m tidal variations of Passamaquoddy Bay (Bay of Fundy) have the potential of between 800 MW to 14 000 MW.

Where are good areas for exploiting tidal energy?

Tidal range varies widely (4.5m–12.4m) from site to site. A tidal range of at least 7 m is required for economical operation and for sufficient head of water for the turbines.

Traditional tidal electricity generation involves the construction of a barrage across an estuary to block the incoming and outgoing tide. The dam includes a sluice that is opened to allow the tide to flow into the basin; the sluice is then closed, and, as the sea level drops, the head of water (elevated water in the basin) using traditional hydropower technology, drives turbines to generate electricity. Barrages can be designed to generate electricity on the ebb tide, or flood tide, or both.

A 240 MW facility has operated in France since 1967; 20 MW in Canada since 1984, and a number of stations in China since 1977. Tidal energy schemes are characterised by low capacity factors.

The waters off the Pacific Northwest are ideal for tapping into an ocean of power using newly developed undersea turbines. The tides along the Northwest coast fluctuate dramatically, by as much as 4.0m a day. The coasts of Alaska, British Columbia and Washington State, in particular, have exceptional energy-producing potential. On the Atlantic seaboard, Maine is also an excellent candidate. The undersea environment is hostile, so the machinery would have to be robust.

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 a 240 MW station at the mouth of the river estuary at La Rance, on the northern coast of France (a large coal or nuclear power plant generates about 1000 MW of electricity). The La Rance generating station has been in operation since 1967 and has been a very reliable source of electricity for France. The La Rance generating station was intended to be one of many tidal power plants in France until their nuclear programme was greatly expanded in the late 1960s.

Studies have been undertaken to examine the potential of several other tidal power sites worldwide. It has been estimated that a barrage across the Severn river in western England could supply as much as 10% of the country's electricity needs.

What is the impact on the environment?

Tidal energy is a renewable source of electricity which does not result in the emission of gases responsible for global warming or acid rain associated with fossil fuel generated electricity. Use of tidal energy could also decrease the need for nuclear power, with its associated radiation risks. Changing tidal flows by damming a bay or estuary could, however, result in negative impacts on aquatic and shoreline ecosystems, as well as on navigation and recreation.

Local tides changed only slightly due to the La Rance barrage, and the environmental impact has been negligible, but this may not be the case for all other sites.

What are the costs of tidal energy?

Tidal power is a form of low-head hydroelectricity and uses familiar low-head hydroelectric generating equipment, such as has been in use for more than 120 years. The technology required for tidal power is well developed, and the main obstacle to increased use of the tides is that of construction costs. There is a high capital cost for a tidal energy project, with a possible 10-year construction period. Therefore, the electricity cost is very sensitive to the interest rates.

The major factors in determining the cost effectiveness of a tidal power site are the size (length and height) of the barrage required and the difference in height between high and low tide. These factors can be expressed in what is called a site's Gibrat ratio. The Gibrat ratio is the ratio of the length of the barrage in metres to the annual energy production in kilowatt hours. The smaller the Gibrat ratio, the more desirable the site. Examples of Gibrat ratios are: La Rance at 0.36; Severn at 0.87 and Passamaquoddy in the Bay of Fundy at 0.92.

Electricity can be generated by water flowing both into and out of a bay. As there are two high and two low tides most days, electrical generation from tidal power plants is characterised by periods of maximum generation with no electricity generation in between. Alternatively, the turbines can be used as pumps to pump extra water into the basin behind the barrage during periods of low electricity demand. This water can then be released when demand on the system is greatest, thus allowing the tidal plant to function with some of the characteristics of a pumped-storage hydroelectric facility.

Adapted from: <http://www.oceanenergycouncil.com/index.php/Tidal-Energy/Tidal-Energy.html>

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Extract 6: Tidal forces

Tidal forces

Consider the gravitational force exerted on the Earth by the Moon. The *tidal* force is the *difference* between the actual force exerted on a piece of Earth matter and the force exerted on the same piece if it were placed at the Earth's centre. See Fig. E6.1.

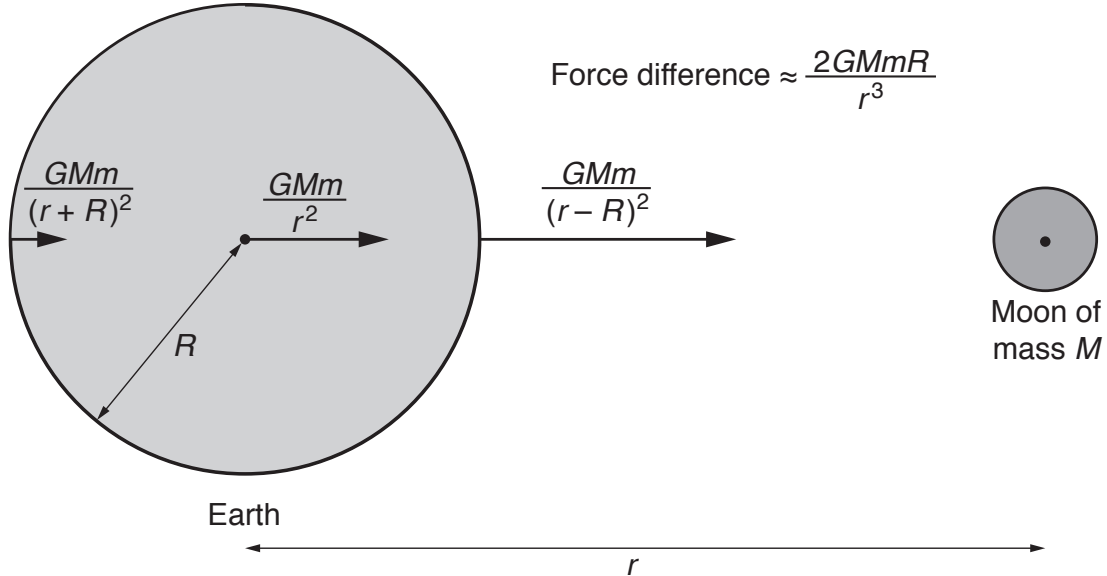


Fig. E6.1 (not to scale)

For example, the Moon's gravitational pull on a 70 kg person located on the Earth's surface with the Moon directly overhead (i.e. on the right in Fig. E6.1) is

$$\frac{70GM}{(r-R)^2} = 2.44 \times 10^{-3} \text{ N}$$

where the Moon's mass M is taken to be 7.3×10^{22} kg, the distance r from the Earth to the Moon is 380 000 km, and the Earth's radius R is 6400 km. The force on the same person located at the Earth's centre would be $70 GM/r^2 = 2.36 \times 10^{-3}$ N. The Moon's tidal force on the person is the small difference between these two forces.

With the help of a little algebra, we can write down an equation for the tidal force exerted by the Moon (of mass M and distance r) on a body (of mass m) placed at various locations on the Earth's surface (assuming that the Earth's radius R is much less than r). When the body is placed along the line joining the Earth to the Moon, the Moon's tidal force is directed away from the Earth's centre and has magnitude

$$\text{tidal force} = \frac{2GMmR}{r^3} .$$

Note that, unlike the familiar inverse-square law of gravity, the tidal force decreases as the inverse cube of the distance between the bodies involved. This rapid decline with increasing distance means that an object has to be very close, or very massive, in order to have a significant tidal effect on another.

Adapted from: <http://astronomy.nju.edu.cn/~lixd/GA/AT4/AT407/HTML/MP0703.htm>

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