



Oxford Cambridge and RSA

**For issue on or after: 13 March 2023**

**A Level Physics B (Advancing Physics)**

**H557/02** Scientific literacy in physics

Advance Notice Article

**To prepare candidates for the examination taken on  
Friday 9 June 2023 – Morning**



### **INSTRUCTIONS**

- Before the exam, read this article carefully and study the content of the learning outcomes for A Level Physics B (Advancing Physics).
- You can ask your teacher for advice and discuss this article with others in your class.
- You can investigate the topic of this article yourself using any resources available to you.
- Do **not** take this copy of the article or any notes into the exam.

### **INFORMATION**

- In the exam you will answer questions on this article. The questions are worth 20–25 marks.
- A clean copy of this article will be given to you with the question paper.
- This document has **8** pages.

### **ADVICE**

- In the exam you won't have time to read this article in full but you should refer to it in your answers.

## Power from Wind and Water

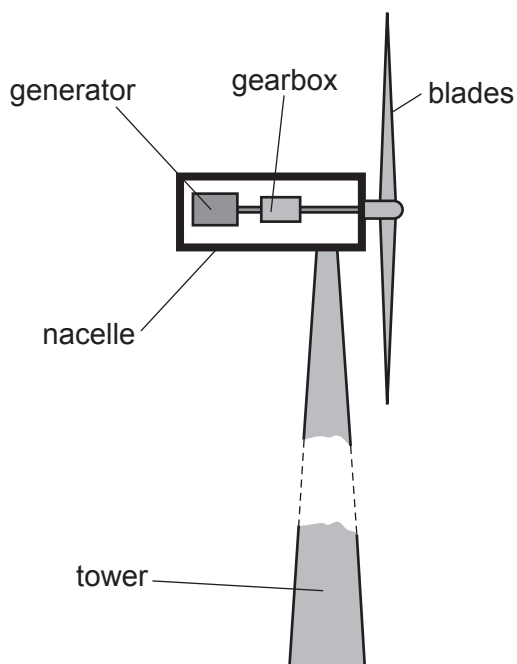
Watermills and windmills have been a feature of many landscapes for hundreds of years. These systems were used for many purposes such as grinding corn or, in the case of watermills, powering textile looms at the birth of the industrial revolution.

- 5 In recent years, governments across the world have looked to reduce the amount of carbon dioxide released in the production of energy. This has brought electricity generation by nuclear, hydroelectric, solar and wind power, amongst other sources, into the 'energy mix' of many countries. The United Kingdom, as a group of islands, is well-suited to use offshore wind power to contribute significantly to our energy needs. Although there are few opportunities  
10 for large-scale hydroelectric power stations such as seen in Norway and in the huge dams in China, energy can be extracted from rivers in small-scale hydroelectric systems.

### Electricity from the wind

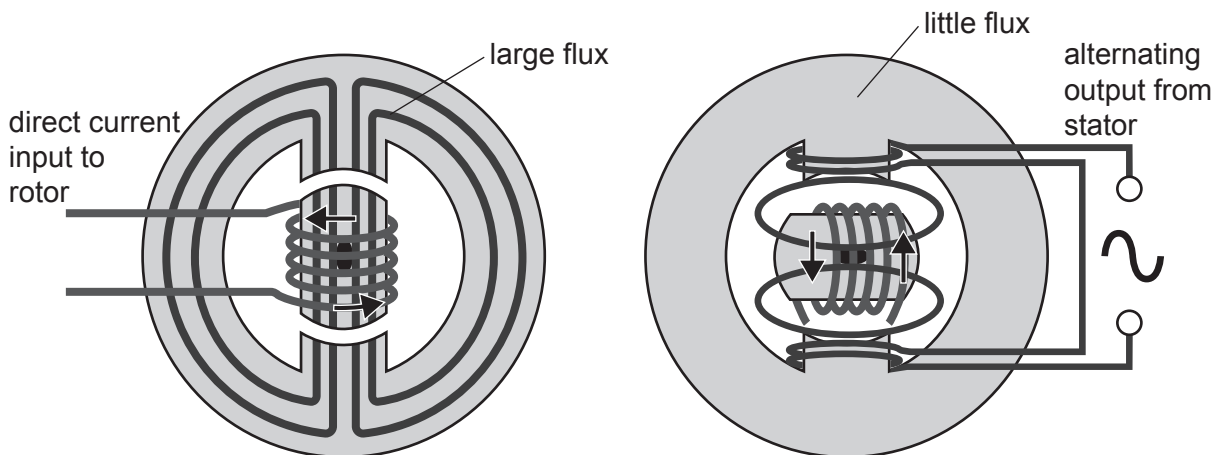
- The kinetic energy of the wind is transferred to the kinetic energy of the rotating blades. The rotation of the blades turns a generator which produces electricity using the principles first  
15 described by Michael Faraday in the 1830s.

**Fig. 1** Schematic diagram of a wind turbine (not to scale).



- Fig. 1** shows a highly simplified diagram of a wind turbine. The wind turns the blades at between 30 and 60 revolutions a minute. The gearbox increases this rate of rotation so that the generator turns at between 1000 and 1800 revolutions per minute. The generator is a more complex affair  
20 than a simple coil turning in a field but the basic principle of electromagnetic induction explains the generation of an a.c. output from even the largest turbines. A magnet or electromagnet, the **rotor**, spins inside coils wound on an iron core, the **stator**, as shown in **Fig. 2**. The flux in the core changes as the magnet spins, changing the flux linkage in the coils, inducing a varying e.m.f. The specific requirements of generation in wind turbines mean that other methods of  
25 electricity generation are also used but these are beyond the scope of this article.

**Fig. 2** A simple generator – note that, for clarity, the stator coils are shown *only* on the second diagram.



### A question of size

30 Wind turbines are getting taller with larger blades. For example, the turbine at Ness Point in Lowestoft, Suffolk, has a blade diameter of 92 m and the nacelle is at a height of 80 m above the ground. The power of the wind in an area  $A$  is given by the equation

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

35 where  $\rho$  is the density of the air and  $v$  is the velocity of the wind. A bigger turbine catches a greater area of wind, increasing the power incident on the turbine blades. Also, wind speed increases with height above the ground. There are many variables at play here, but the

mathematical expression  $v_h = v_{10} \left( \frac{h}{10\text{m}} \right)^{\frac{1}{7}}$  gives an indication of how the velocity of the wind at height  $h$  is related to the velocity at a height of 10 m.

40 A turbine does not stop the flow of the wind but slows it down and spreads it out, so the power extracted by the turbine will be considerably lower than the power of the wind at any moment. It is a reasonable estimate to say that the turbine extracts about 40% to 50% of the available energy from the wind.

## Farming wind

Fig. 3 shows a part of the Walney wind farm off the coast of north-west England.

Fig. 3



- 45 There are 189 turbines in a number of groupings in this area of the coast, providing a total power of about 1 GW in the best conditions. This compares well to large plants using non-renewable fuel but, of course, the wind doesn't blow all the time.

- 50 Interestingly, the size of the turbine blades does not affect the power that can be extracted from a given area of land (or sea) surface. Turbines cannot be placed closer than about five times their diameter without significant power loss – one turbine will steal the energy of the wind from nearby turbines. Bigger turbines need to be spaced further apart so fewer can fit in a given area. However, it is still advantageous to use tall towers to catch the faster winds at greater heights and there are other advantages to using fewer, larger turbines.

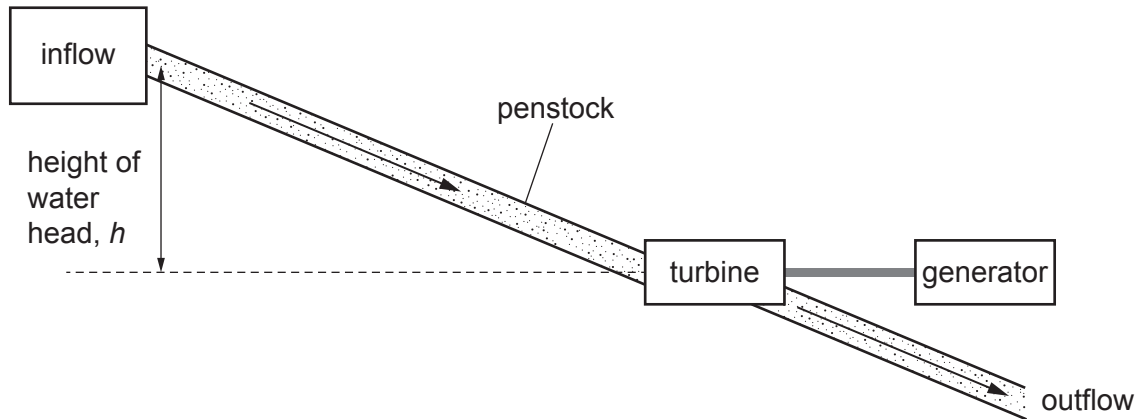
### Storing and sharing energy

- 55 The wind does not always blow when you want it. There will be times when the electrical power required exceeds that which is available through wind power, and other times when more power is available from wind farms than is needed. To help reduce this problem, some of the electricity generated in times of high winds can be stored in other forms such as gravitational potential energy or used by other countries.
- 60 A dramatic example of this is the North Sea interconnector. This stretches 720 km from the coast of north-east England to Norway. When there is spare capacity in England, Norway receives power through the cable, reducing the need for using its own energy stores. When England requires more power, it is provided via the cable from a hydroelectric station in Norway.

### Small-scale hydropower

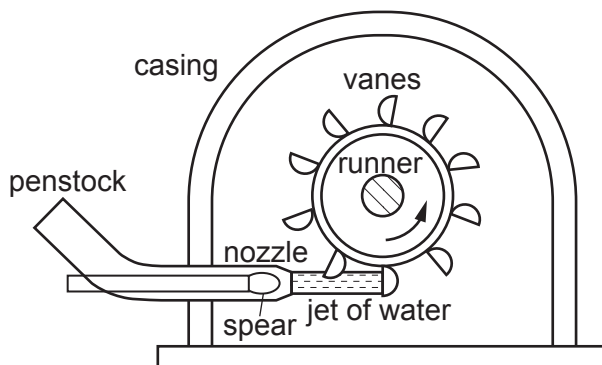
- 65 A proportion of the water flowing in a river can be diverted through pipes to power a turbine downstream. **Fig. 4** shows a schematic diagram of such a system.

**Fig. 4** (not to scale)



These small-scale generators often use Pelton turbines which take water through a tube called a penstock and direct a jet (or jets) of water onto a series of vanes as shown in **Fig. 5**.

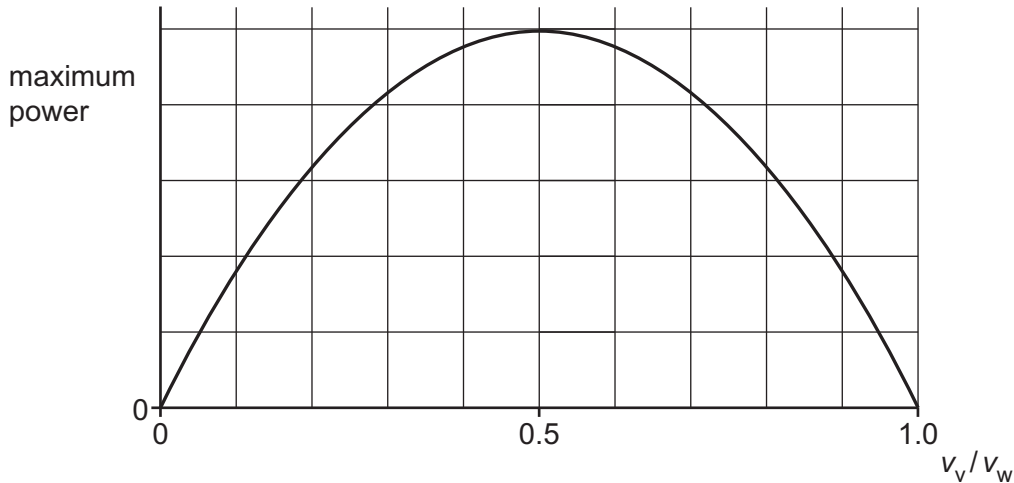
- 70 **Fig. 5** Pelton turbine



The impulse exerted by the water causes the runner to rotate. The 'spear' is used to control the flow of water onto the turbine.

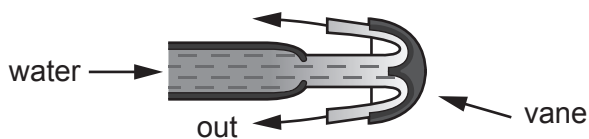
- 75 **Fig. 6** shows how the maximum possible power delivered by the turbine varies with the ratio of water velocity  $v_w$  and vane velocity  $v_v$ . No power is produced by the turbine when the vane velocity is zero or when the vane velocity is equal to that of the water.

Fig. 6



The bucket-shaped vanes are designed to split the water into two streams which then curve round and leave the bucket after travelling through an angle of as near to  $180^\circ$  as possible, without interfering with the water striking the vane from the nozzle (**Fig. 7**). Careful design considerations allow Pelton turbines to have efficiencies as high as 95%.

Fig. 7



### Towards a low-carbon energy supply

Although the United Kingdom is not considered a sunny country, solar power also contributes to our energy mix. For example, as this article is being written, 58% of the energy used in southern England is generated from solar sources with 3% coming from wind, whereas in the North West 32% of the energy used is coming from wind and only 4% from solar.

Developing a low-carbon energy supply requires careful positioning of solar farms, wind farms and other systems to maximise the geographical and meteorological variation across the country. Modern wind and water turbines are far removed from the picturesque windmills and waterwheels seen in old illustrations, but they use exactly the same basic principles and form a link with our industrial and pre-industrial past.



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