Oxford Cambridge and RSA

For issue on or after: 13 March 2025

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Advance Notice Article

To prepare candidates for the examination taken on Monday 9 June 2025 – Morning

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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

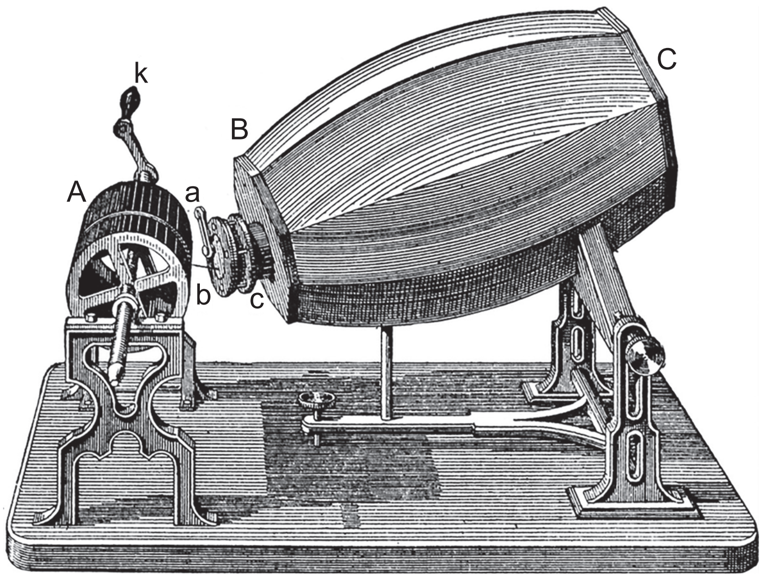
- In the exam you won't have time to read this article in full but you should refer to it in your answers.

Capturing the moment

Recorded sound is all around us. We can choose what we listen to streamed onto our mobiles or computers or played back via memory chips, CDs and vinyls. Some of this audio material is produced purely electronically, but the first, crucial element in recording live sound in any format is the microphone. The first patent for a transducing microphone (which turns air pressure variations into an electrical signal) was filed on June 4th 1877 by Emile Berliner. This was the ‘carbon microphone transmitter’ which was used for telephones rather than recording sound for posterity.

To find the first recording of human singing we go back a further seventeen years. The Frenchman Eduoard-Leon Scott de Martinville developed a method of recording sounds as a written trace which he named the phonoautograph and patented in 1857. Sound waves, such as from a voice, enter a horn at the end of which is a diaphragm which oscillates at the same frequency as the waves striking it. There is a stylus (originally a boar’s bristle) attached to the diaphragm which scratches a glass surface covered in soot, creating an image called a phonoautogram. The surface is pulled along at a typical speed of $1\,\mathrm{m\,s^{-1}}$ and the stylus produces a pattern rather similar to one you might have seen on an oscilloscope connected to a microphone.

Fig. 1



A later version of the phonoautograph. The stylus is labelled ‘b’, the sound to be recorded enters the horn at ‘C’. The cylinder ‘A’ is rotated and the stylus leaves a trace on the surface.

In 1860, Scott de Martinville recorded himself singing the song ‘Au clair de la Lune’. The movement of the stylus is very small so the wobbles on the line in the soot are very small, there is a very poor signal-to-noise ratio. However, this wobbly line has been digitally scanned and converted into an audio file. You can find this here: https://commons.wikimedia.org/wiki/File:Au_Clair_de_la_Lune_(1860)_new.ogg . This is the oldest recording of the human voice yet retrieved.

Fig. 2

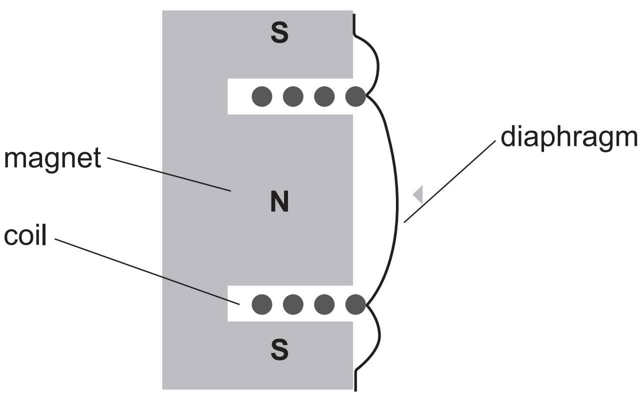
Sir Edward Elgar conducting a recording in the 1920s. The sound is captured in the horn which vibrates a stylus that scratches a trace onto a wax cylinder or disc. This image is interesting both technologically and socially – all the musicians are men of a similar class, formally dressed.

The advent of the electric transducing microphone changed recording forever, and also changed performances. For example, a whole new style of singing developed, ‘crooning’, in which the singer could sing softly into the microphone and allow the amplifier to increase the amplitude of the sound. Microphone technique is still an important skill for all performers across all musical genres.

There are many types of electric microphones in use today – think of the size of the microphones that musicians and singers use on stage compared to long ‘boom’ microphones you see in news reports, or the far smaller microphones found in mobile phones and hearing aids. All these microphones have one thing in common: a method of converting sound pressure variation into electrical variation.

Dynamic microphones rely on the physics of electromagnetic induction to generate a varying electrical signal. The diaphragm oscillates at the same frequency as the pressure variation incident upon it. This oscillates the coil in the magnetic field, inducing an emf which will drive a current that can be amplified and recorded or used to drive a loudspeaker.

Fig. 3 Some components of the dynamic microphone



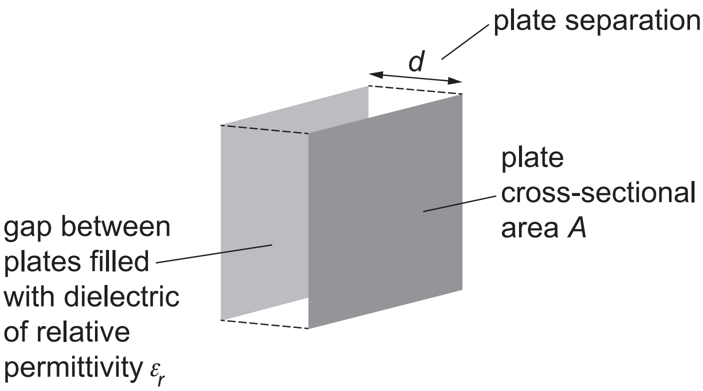
Dynamic microphones are robust and can be surprisingly small but there are problems that need to be overcome. Individual components of the microphone, such as the diaphragm have natural frequencies of oscillation which can lead to resonances which distort the signal to the amplifier. Designers overcome this problem by damping some resonances and creating more resonance frequencies within the body of the microphone so that, as far as possible, the frequency response is ‘flat’.

The sensitivity of dynamic microphones, measured in mV/Pa, is related to the amplitude of oscillation of the diaphragm. This falls off at frequencies of over 16 kHz and is near zero at 20 kHz. This fall-off is due to the response of the oscillating mass (the diaphragm and coil) to the accelerating force (the pressure differences as sound waves strike the diaphragm). Although the range of frequencies affected is higher than the frequency of the notes we hear in music (the highest note on a piano is about 4200 Hz), losing these higher frequencies will affect the accuracy of the recording of complex waveforms.

The amplitude of the emf generated is equal to the rate of change of flux linkage. This has consequences for the relative phases of the sound wave and the electrical variation generated.

Condenser microphones rely on the physics of the capacitor. The capacitance of a parallel plate capacitor is given by the equation $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ where ε_0 is the permittivity of free space, ε_r is the relative permittivity of the dielectric, A is the cross-sectional area of the plates and d is the separation of the plates.

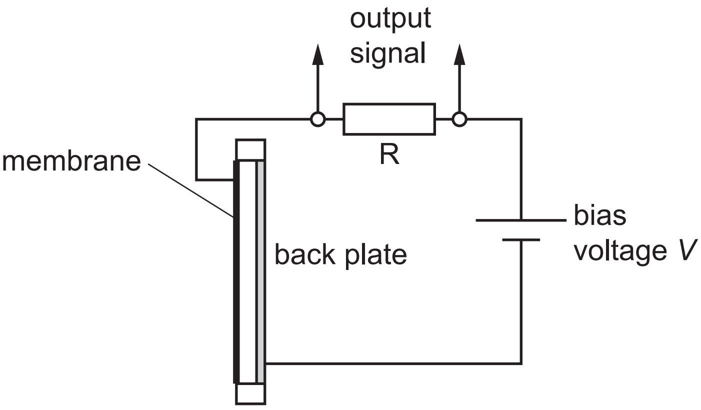
Fig. 4 Parallel plate capacitor



Condenser microphones have a very thin membrane (the diaphragm) as one plate of the capacitor and a fixed metal sheet as the second plate. The dielectric between the plates is air. Sound waves cause the membrane to oscillate, changing the distance between the two plates which, from the equation above, will change the capacitance of the capacitor.

Fig. 5 shows a simplified circuit for the condenser microphone.

Fig. 5



The ‘bias voltage’ keeps the potential difference of the capacitor constant. When the capacitance changes in response to sound waves incident on the membrane, charge moves on or off the capacitor, producing a potential difference across the resistor R, this is the output signal.

The signal from a condenser microphone is in phase with the pressure variation, unlike the dynamic microphone. The low-mass membrane has little inertia and so condenser microphones are likely to be more sensitive to high-frequency sounds than dynamic microphones. The membranes are quite fragile which means that condenser microphones are less robust than dynamic microphones and need to be handled with care.

Electret microphones also use the physics of the capacitor. An electret (from **electr**ostatic magn**et**) is a material which holds its charge rather like a permanent magnet holds its magnetism. These microphones are found in smart phones, hearing aids and many other devices.

Fig. 6 the principle of an electret capacitor.

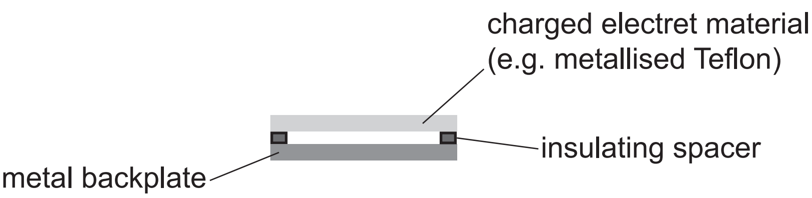
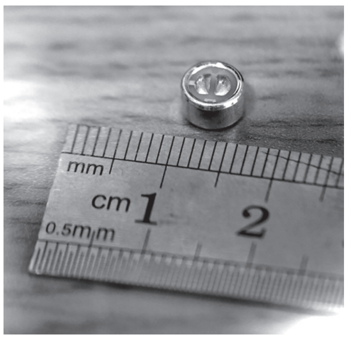


Fig. 7 electret capsule



The electret capacitor capsule can be considered as two capacitors in series. The electret material (the membrane) has a charge separation between its two faces. The capacitance of the membrane layer, C_M, is given by $C_M = \dfrac{\varepsilon_0 \, \varepsilon_r \, S}{h}$ where S is the surface area and h is the thickness of the layer. The charge on the lower surface of the electret layer induces a charge on the metal backplate, producing an air-gap capacitor C_G of value $C_G = \dfrac{\varepsilon_0 \, S}{d}$ where d is the width of the air gap. (The surface area of the membrane and metal plate are equal.)

Sound waves incident on the electret layer produce oscillations which changes the distance, *d*, between the electret and the backplate, changing the capacitance. As the charge on the electret does not change, the potential difference across the two layers will change. This potential difference is applied to a further circuit to produce the output signal.

MEMS (microelectricalmechanical systems) microphones take miniaturisation further. These are tiny condenser microphones which are etched onto silicon chips. These are now found in many of the uses listed for electret microphones.

Consumers now expect accurate recordings from relatively cheap, robust and small microphones. Although the basic physics of the microphone is fairly straightforward, as has been discussed in the article, modern miniaturised microphones rely on sophisticated electronics to amplify, digitise and store the sounds they record. But we should never forget what an incredible thing it is to have fleeting sounds captured forever, whether these be of the natural world, relatives and friends, or musical performances. We can capture, accurately, any moment we choose. Recording has certainly come a long way from the phonoautograph.

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