OCR
RECOGNISING ACHIEVEMENT

Monday 11 June 2012 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495 Field and Particle Pictures

Candidates answer on the Question Paper.

OCR supplied materials:
- Data, Formulae and Relationships Booklet (sent with general stationery)
- Insert (inserted)

Other materials required:
- Electronic calculator
- Ruler (cm/mm)

Duration: 2 hours

Candidate forename		Candidate surname	

Centre number						Candidate number				

INSTRUCTIONS TO CANDIDATES

- The Insert will be found in the centre of this document.
- Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.
- Use black ink. HB pencil may be used for graphs and diagrams only.
- Answer **all** the questions.
- Read each question carefully. Make sure you know what you have to do before starting your answer.
- Write your answer to each question in the space provided. Additional paper may be used if necessary but you must clearly show your candidate number, centre number and question number(s).
- Do **not** write in the bar codes.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this paper is **100**.
- You may use an electronic calculator.
- Where you see this icon you will be awarded marks for the quality of written communication in your answer.
  This means for example, you should:
  - ensure that text is legible and that spelling, punctuation and grammar are accurate so that the meaning is clear
  - organise information clearly and coherently, using specialist vocabulary when appropriate.
- You are advised to show all the steps in any calculations.
- This document consists of **24** pages. Any blank pages are indicated.
- The questions in Section C are based on the material in the Insert.

Answer **all** the questions.

Section A

1 Fig. 1.1 shows an ideal transformer.

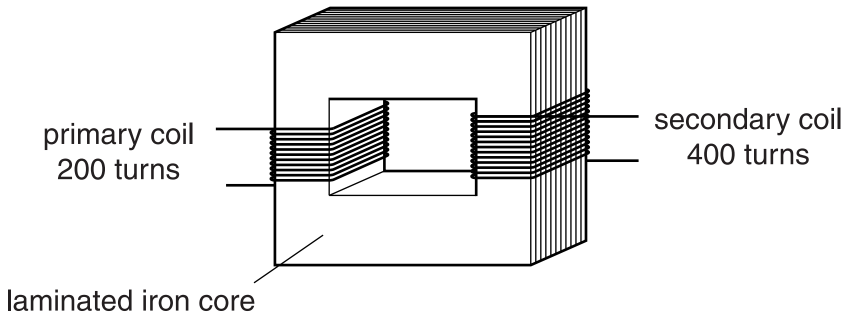


Fig. 1.1

A 50 Hz alternating p.d. of 12 V is applied to the primary coil.

(a) Choose the correct statement from the sentences below:

A The p.d. across the secondary coil is 24 V, frequency 100 Hz.

B The p.d. across the secondary coil is 6.0 V, frequency 50 Hz.

C The p.d. across the secondary coil is 24 V, frequency 50 Hz.

D The p.d. across the secondary coil is 6.0 V, frequency 100 Hz.

The correct statement is .... **[1]**

(b) The current in the primary coil is 1.8 A.

Calculate the current in the secondary coil.

current = ... A **[1]**

2 Here is a list of particles.

electron

neutron

photon

positron

(a) Which particle is composed of quarks?

.... **[1]**

(b) Which particle has the highest rest energy? .... **[1]**

3 The electric field strength at a distance r from a point charge Q is given by

$$E = \frac{kQ}{r^2}$$

where k is a constant.

Show that the units of k are $\mathrm{N\,m^2\,C^{-2}}$.

[1]

4 Fig. 4.1 shows a sketch graph of average binding energy per nucleon against nucleon number.

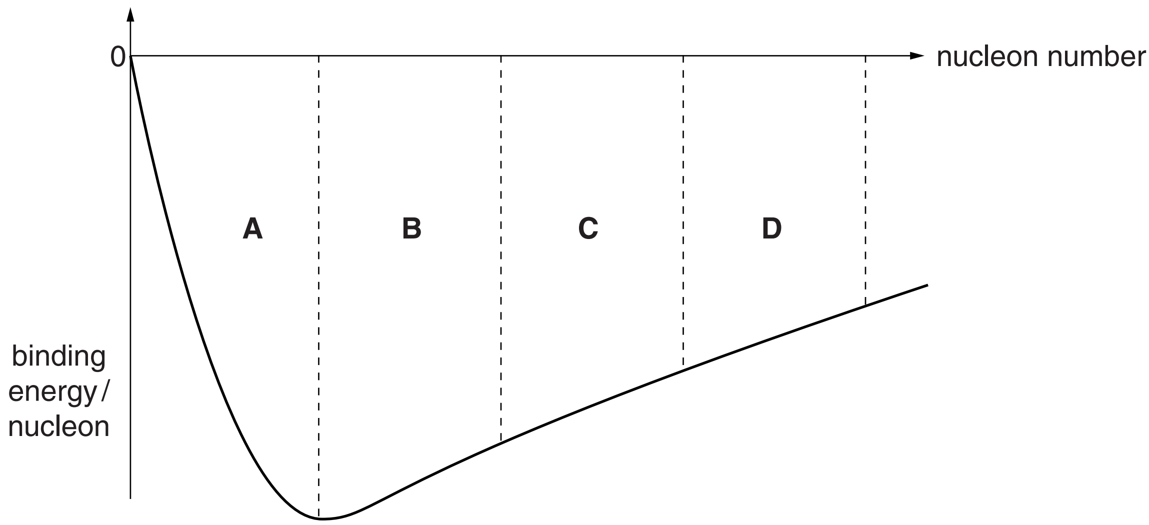


Fig. 4.1

(a) The Sun releases energy through nuclear **fusion**. State in which region, **A**, **B**, **C** or **D** on the graph, nuclei may release energy through fusion.

region .... **[1]**

(b) The Sun releases energy at a rate of 4×10^{26} W.

Calculate the mass lost by the Sun in one second.

$c = 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$

mass lost in one second = ... kg **[2]**

5 Fig. 5.1 shows a point **X** near an isolated proton.

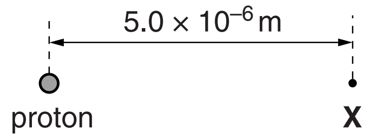


Fig. 5.1

The field strength at **X**, 5.0×10^{-6} m from the centre of the proton, is 58 N C^{-1}.

(a) Calculate the potential at **X**.
$k = 9.0 \times 10^{9}$ N m^{2} C^{-2}
charge on a proton $= 1.6 \times 10^{-19}$ C

potential = ... J C^{-1} **[2]**

A second proton moves to a position as shown in Fig. 5.2.

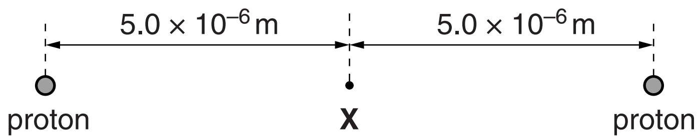


Fig. 5.2

(b) State the field strength at **X** for the situation in Fig. 5.2.

[1]

(c) State how the potential at **X** in Fig. 5.2 compares with your answer to **(a)**.

[1]

6 The centripetal force F on a charge q moving at right angles to a magnetic field is given by

$$F = q\,v\,B$$

where v is the speed of the particle in the field.

Combine this equation with that for centripetal force $F = mv^2/r$ to show that a singly-charged ion of momentum $2.5 \times 10^{-20}\,\mathrm{kg\,m\,s^{-1}}$ travelling at right angles to a magnetic field of strength 0.70T will move in a circular path of radius about 0.2m.

$e = 1.6 \times 10^{-19}\,\mathrm{C}$

[2]

7 In April 1986 the Chernobyl nuclear reactor released radioactive caesium-137 into the atmosphere. Caesium-137 has a half-life of 30.1 years.

Show that, in June 2012, approximately 26 years after the release, less than 60% of the caesium-137 remains.

[3]

8 Fig. 8.1 shows the direction of a current I in a wire at right angles to a field of flux density B.

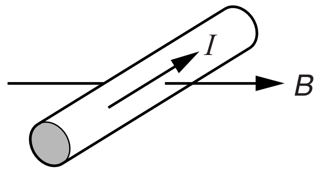


Fig. 8.1

Calculate the force on a 15 cm length of wire in a field of flux density 400 mT when the wire carries a current of 0.23 A.

force = ... N **[2]**

[Section A Total: 19]

Section B

9 This question is about the behaviour of electrons when passing near nuclei.

When an electron passes near a nucleus it is deflected as shown in Fig. 9.1.

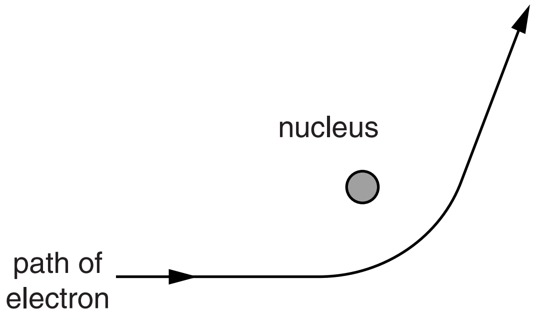


Fig. 9.1

(a) Explain why the electron follows a path of the shape shown. You may add arrows to Fig. 9.1 indicating magnitude and direction of forces on the electron.

In your answer you should make clear how the force on the electron varies along its path.

[3]

(b) At high energies the momentum p of a particle is given by

$$p \simeq \frac{E}{c}$$

where E is the energy of the particle and c is the speed of light.

(i) Show that $\frac{E}{c}$ has the units of momentum.

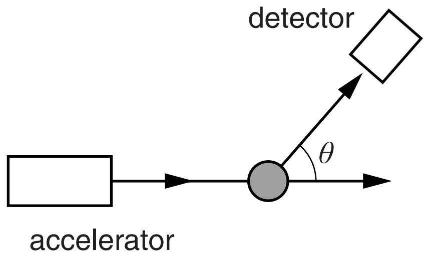
[2]

(ii) Show that an electron accelerated to a high energy of 6.8×10^{-11} J (425 MeV) will have a de Broglie wavelength of about 3×10^{-15} m.

$h = 6.6 \times 10^{-34}$ J s
$c = 3.0 \times 10^{8}$ m s^{-1}

[2]

(c) Fig. 9.2 shows how the number of 425 MeV electrons scattered by carbon nuclei varies with the scattering angle. The graph shows a clear diffraction minimum. The nuclei diffract high energy electrons like dust particles diffract light.



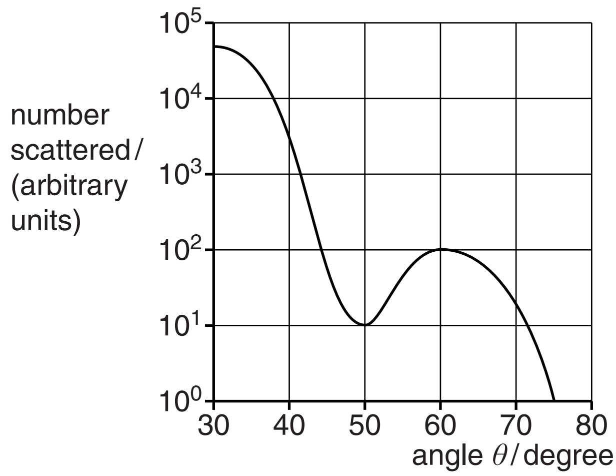


Fig. 9.2

The angle of the first diffraction minimum in such a pattern is given by the equation

$$\sin\theta = \frac{1.2\lambda}{b}$$

where b is the diameter of the diffracting object and λ is the wavelength of the electrons. Use data from the graph to estimate the diameter of the carbon nuclei in the sample.

diameter = ... m **[3]**

[Total: 10]

10 This question is about using accelerated protons in medicine.

The protons are accelerated to kinetic energies of 220 MeV. The rest energy of a proton is 940 MeV.

(a) **(i)** State what is meant by the term *rest energy*.

[1]

(ii) Show that the relativistic factor γ for these accelerated protons is about 1.2.

[1]

(iii) Show that these protons are travelling at about 0.6 c.

[2]

(b) In a medical procedure a cluster of cells of total mass 3.0×10^{-4} kg is irradiated with 220 MeV protons.

Show that it will take at least 10^5 protons to deliver an effective dose equivalent of 125 mSv to the cluster of cells.

$e = 1.6 \times 10^{-19}$ C
quality factor of protons = 10

[3]

(c) The effect of a proton beam on tissue can be modelled by passing the proton beam through water. Energy is transferred from each proton when it ionises particles along its path. Fig. 10.1 shows how the energy of a proton beam varies along the path of the beam through water.

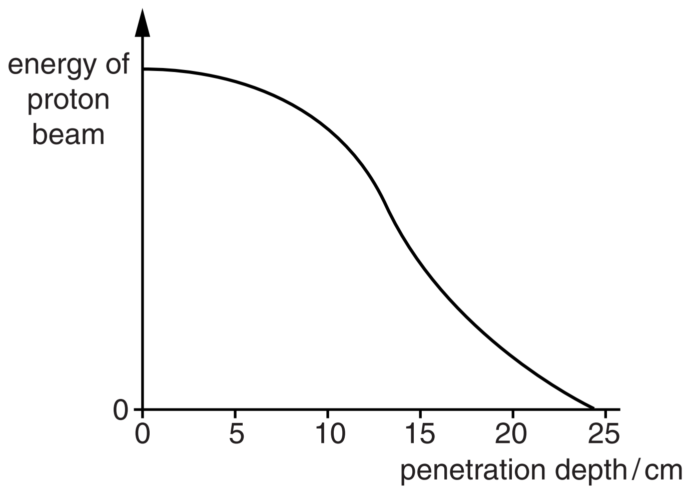


Fig. 10.1

(i) Use information from the graph to estimate the depth at which the beam ionises the greatest number of particles per cm. Explain how you reached your answer.

depth = ... cm

[3]

(ii) Explain why the graph shows that your answer to **(b)** must be a minimum value.

[2]

[Total: 12]

11 This question is about using an electric field to deflect falling particles of material.

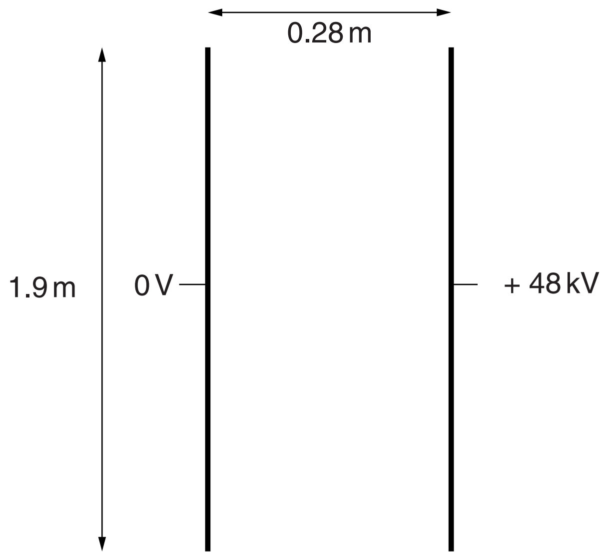


Fig. 11.1

Fig. 11.1 shows two vertical metal plates connected to a 48 kV supply.

(a) **(i)** Draw five lines to represent the electric field between the plates in Fig. 11.1. **[2]**

(ii) Add the 24 kV equipotential to the diagram. Label the line. **[1]**

(b) Use data from the diagram to show that field strength between the plates is about 0.2 MV m^{-1}.

[1]

(c) A grain of mass 1.3×10^{-6} kg enters the region between the plates, falling at constant (terminal) vertical velocity of $0.8\,\mathrm{m\,s^{-1}}$. The grain carries an electric charge of $+2.2 \times 10^{-13}$ C.

(i) State why the data above suggests that the vertical force due to air drag is about 1×10^{-5} N.

$g = 9.8\,\mathrm{N\,kg^{-1}}$

[1]

(ii) The horizontal force on the grain is much smaller. Show that the horizontal force is about 4×10^{-8} N.

[1]

(iii) Show that the horizontal distance moved by the grain as it falls through the 1.9 m plates is of the order of 0.1 m. Any horizontal drag forces can be ignored.

[3]

(d) Suggest and explain how the horizontal distance would change if the separation of the plates was doubled but all other factors remain constant.

[3]

[Total: 12]

12 This question is about magnetic circuits.

The permeance Λ of a magnetic circuit is given by the equation

$$\Lambda = \frac{\Phi}{NI}$$

where: Φ is the magnetic flux in the circuit
N is the number of turns of the coil
I is the current in the coil

A magnetic circuit is illustrated in Fig. 12.1.

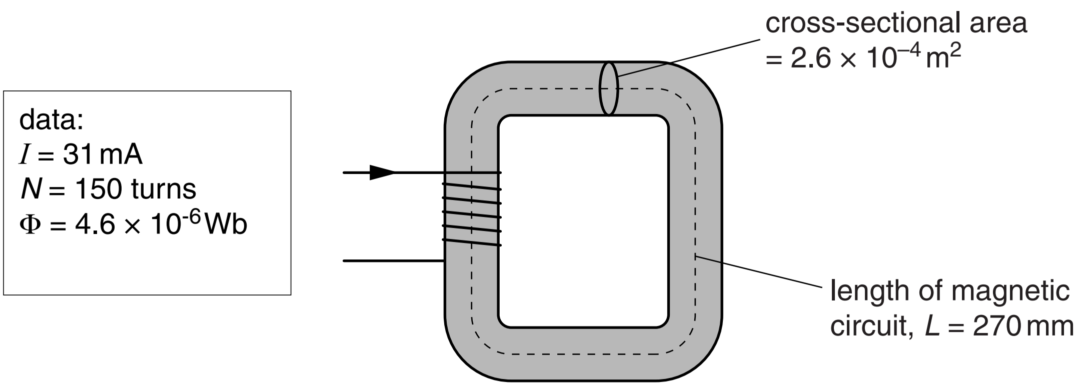


Fig. 12.1

(a) Calculate the permeance of the circuit in Fig. 12.1.

permeance = ... unit .... **[2]**

(b) The permeance of a magnetic circuit is also given by the equation

$$\Lambda = \frac{\mu A}{L}$$

where μ is the permeability of the iron in the core, A the cross-sectional area of the core and L the length of the magnetic circuit.

Use data from Fig. 12.1 and your answer to **(a)** to calculate the permeability of the iron in the core.

permeability of iron in the core = ... $\text{Wb A}^{-1}\text{m}^{-1}$ **[2]**

(c) A crack develops across the core, making an air-gap running across its entire cross-section as shown in Fig. 12.2.

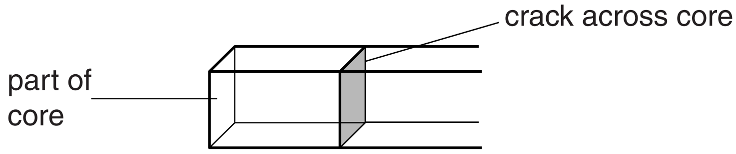


Fig. 12.2

(i) State how the permeability of air compares to that of iron.

[1]

(ii) Explain why the flux through the core is reduced when the core develops a crack. You may find it useful to refer to an equation given earlier in the question.

[2]

(d) A student believes that the equation $\Lambda = \mu A/L$ shows that the **permeability** of the iron in the core has also reduced. Discuss whether you agree with the student or not.

[2]

[Total: 9]

[Section B Total: 43]

Section C

These questions are based on the Advance Notice.

13 Explain how brittle fracture occurs in rocks under stress, starting at the cracks in the rock (lines 6–7 in the article). You may use diagrams in your answer.

[2]

[Total: 2]

14 Use the data given in Fig. 2 in the article to show that

(a) a surface wave **L** would take less than four hours to travel once around the circumference of the Earth

radius of Earth = 6400 km

[1]

(b) the **P** and **S** waves have the same wavelength.

[2]

[Total: 3]

15 Explain how a combination of transverse and longitudinal waves can result in vibrations in all three spatial directions (lines 9–10 in the article). You may find drawing a diagram useful in your answer.

[3]

[Total: 3]

16 A **P** wave travelling at 6.0 km s^{-1} meets a boundary between two rock types at an angle of incidence of 30° and passes through it at an angle of refraction of 21°.

Use the information given about wave refraction in Box 1 in the article to calculate the speed of the wave in the second type of rock.

speed = ... m s^{-1} **[3]**

[Total: 3]

17 **(a)** Explain why it is important that the natural frequency of the seismometer is deliberately **not equal** to that of the vibrations caused by earthquakes.

[2]

(b) Show that the effective length L of the pendulum in a Milne seismometer (Figs. 3 and 4 in the article) needs to be about 100 m in order for it to have a frequency less than that of the lowest frequency waves (**L** waves, see Fig. 2 in the article).

natural frequency of a simple pendulum, $f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$

where $g = 9.8\,\text{m}\,\text{s}^{-2}$

[2]

(c) Hence calculate the angle α at which the boom needs to be tilted, if it has a length of 1.0 m.

α = ... degrees **[2]**

[Total: 6]

18 Like many seismometers, the Milne design incorporates a large mass which 'remains essentially motionless' when the ground beneath it vibrates. Lines 42–43 in the article list the factors involved in ensuring that this occurs.

(a) Explain how the combination of a large mass and a small force ensures that the mass 'remains essentially motionless'.

[2]

(b) Suppose you could have a pendulum of length 100 m. Explain why the accelerating force on the mass would be very small for a displacement of a few millimetres.

[2]

[Total: 4]

19 Earthquake magnitude can be measured using the Richter Scale (lines 52–54 in the article).

(a) Calculate how many times greater the shaking amplitude of a magnitude 6.0 earthquake is than one of magnitude 4.0. Explain how you reached your value.

answer .... **[2]**

(b) Using the relationship given in line 56 in the article, calculate how many times greater the energy released by a magnitude 6.0 earthquake is than one of magnitude 4.0.

answer .... **[2]**

[Total: 4]

20 The relative movement of the mass and base (Fig. 4 in the article) is detected using a magnet attached to the mass and a coil attached to the base.

(a) Explain how this movement can produce an emf.

[2]

(b) Here are some data for a particular magnet and coil arrangement used to detect vibrations in a seismometer (lines 45–48 in the article). The coil is square and its area is completely contained within the area of the uniform magnetic field at right angles to the plane of the coil.

strength of magnetic field = 0.15 T
cross sectional area of coil = $4.0\,\text{cm}^2$
number of coil turns = 200

(i) Show that the flux through the coil is greater than 5×10^{-5} Wb.

[2]

(ii) Hence calculate the flux linkage through the coil.

flux linkage = ... Wb turns **[1]**

(iii) During an earthquake, the ground shakes. This causes the coil to move a distance of 3 mm out of the magnetic field at an average speed of $1.8 \times 10^{-3}\,\text{m s}^{-1}$.
The flux linkage reduces to half its original value as the coil moves partially out of the magnetic field.

Calculate the magnitude of the emf induced in the coil as a result of this motion.

induced emf = ... V **[4]**

[Total: 9]

21 The seismometer is damped to reduce unwanted vibration. One method of damping is mentioned in lines 66–68 in the article, using an aluminium plate moving in a magnetic field. With particular reference to induced voltage and energy transfers, describe how this arrangement produces the damping required.

You should make each step of your argument clear.

[4]

[Total: 4]

[Section C Total: 38]

END OF QUESTION PAPER

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Monday 11 June 2012 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495 Field and Particle Pictures

INSERT

G412100612

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- This Insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER / INVIGILATOR

- Do not send this Insert for marking; it should be retained in the centre or destroyed.

The Trembling Earth

It has been estimated that every day thousands of earthquakes take place throughout the world. Most go un-noticed but others can cause widespread devastation. Measuring and monitoring earthquake activity is a very important and well-developed area of scientific study, but the ability to predict earthquakes remains much more elusive.

There are many types of earthquake, generally caused by the movement of the tectonic plates that make up the Earth's outer layer (the crust). Such movements lead to the build up of stress in rocks and when the stress exceeds the elastic limit of the rocks, brittle fracture occurs. As the rocks break, transverse and longitudinal waves are produced and spread out in all directions through the body of the Earth (Fig. 1). These waves emerge at the surface as disturbances and vibrations which can be detected in all three spatial directions.

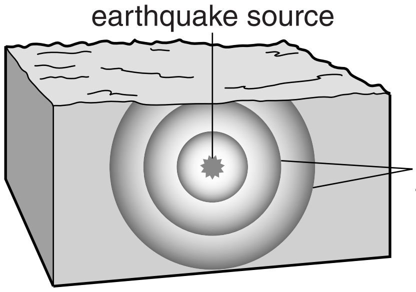


Fig. 1: seismic activity within the Earth as sources of waves

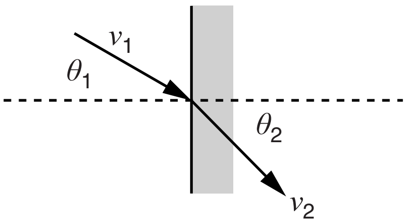
The wave motion within the Earth and at its surface is very complicated. In straightforward models, there are three main types of wave produced, some properties of which are summarised in Fig. 2. One of the factors affecting the speeds of the waves is the density of the material through which they travel. Since this varies considerably with depth, refraction of the waves takes place (see Box 1), studies of which can reveal the internal structure of the Earth in detail. The instruments used to detect the surface vibrations these waves produce are called **seismometers** and many of those in use today are still based on a design from the 19th century.

wave	type	typical frequency (Hz)	typical speed ($km\,s^{-1}$)
primary, **P**	longitudinal	1.00	6
secondary, **S**	transverse	0.50	3
surface, **L**	transverse	0.05	3

Fig. 2: table summarising some properties of seismic waves.
The speeds are for waves at or near the surface of the Earth.

Box 1: Snell's Law and wave refraction

If a wave passes from one medium into another with a different refractive index the speed of the wave will change. If the wave strikes the boundary between the two media at an angle θ_1 to the normal, the wave will change direction as it crosses the boundary, moving now at an angle θ_2.



The ratio of the sines of these two angles is the same as the ratio of the respective speeds of the wave in the two media i.e. $\frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2}$.

Early days

Perhaps the earliest record of a device that can be called a seismometer is that of the instrument designed by the Chinese scholar Chang Heng in AD 132. His ornate design, featuring dragons and toads, probably used a loosely-hanging rod which, when disturbed would knock a marble off a ledge to register the movement. There was little development for a long time after this and the next big step forward in seismometer design did not come until the 1880s when three British scientists, Ewing, Milne and Gray, were studying earthquakes in Japan. Their various designs used large, suspended masses as fixed points of reference. Being fixed, the motion of the shaking Earth during a quake could be measured relative to the large suspended mass enabling observations and records of the vibrations to be made.

Milne's design

Although many designs have evolved from those early instruments, perhaps the best-known is that attributed to John Milne (1883), still widely used. This is sometimes referred to as the "garden-gate" design: see Figs. 3 and 4. The arrangement is tilted so that the boom to which the large mass is attached lies at a small angle, α, to the horizontal. If the mass is disturbed, it will oscillate with simple harmonic motion, moving through an arc equivalent to the path that would be described by a simple pendulum of length L, as given in Fig. 4. The figure shows how this effective length L is equal to $d/\sin\alpha$, where d is the length of the boom, so that the smaller the angle of tilt, the smaller the natural frequency of the swinging mass.

The natural frequency of this oscillation is important because the seismometer will be most effective at frequencies above this. The waves generated by most earthquakes produce ground vibrations of frequencies greater than 0.05 Hz, so the seismometer will be designed such that its natural frequency is no more than this. The rigid base and frame are attached to the ground and so will vibrate with it. Meanwhile, the large mass, which is suspended from the base and frame, remains essentially motionless, due to a combination of the small force trying to accelerate it, the high frequency of that force and, mostly, the great mass it possesses.

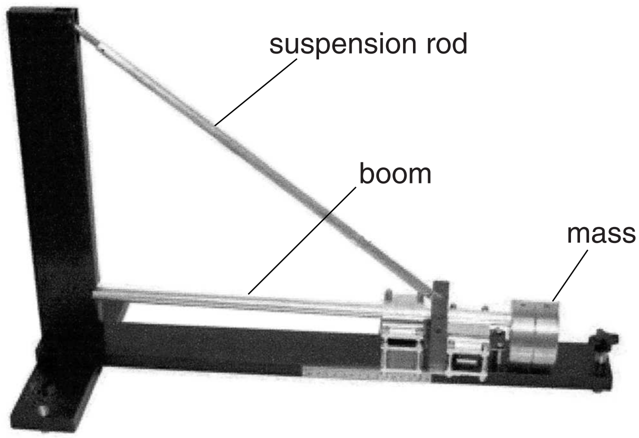


Fig. 3: photograph of a “garden-gate” (Milne) seismometer

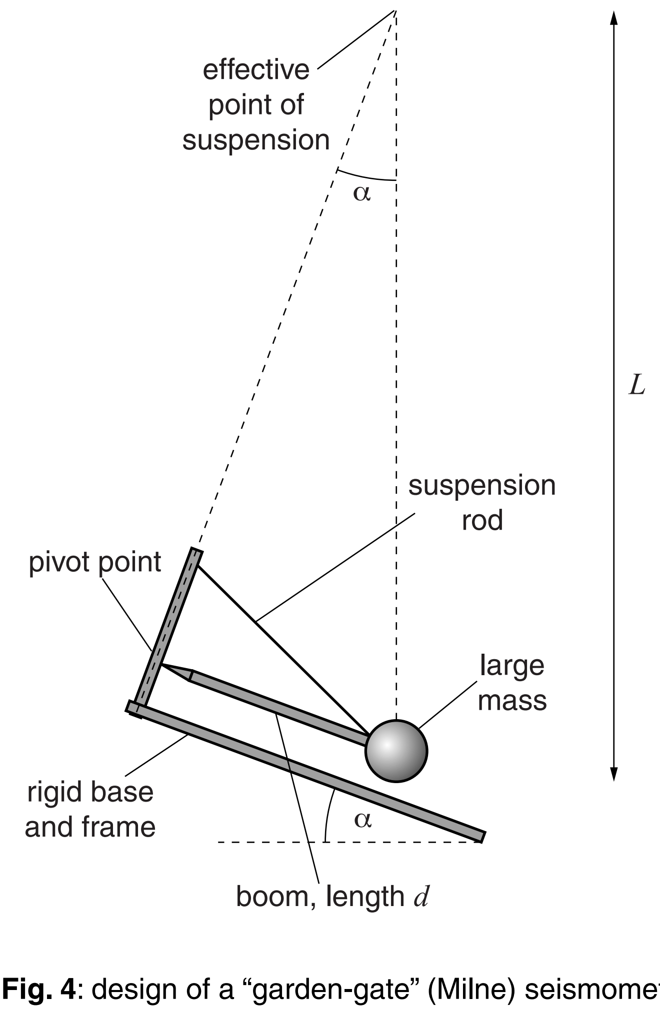


Fig. 4: design of a “garden-gate” (Milne) seismometer

The output

During an earthquake, therefore, there is relative motion between the ground and the mass. If a magnet is attached to the mass and this magnet sits in a coil of wire attached to the base, any relative motion between them will induce an emf and it is this signal that is used to monitor the seismic vibrations. The magnitude of the output will actually be a measure of the speed of the magnet relative to the coil, but it is possible from this information to deduce the amplitude of the movement as well. Manufacturers of the most sensitive instruments claim that vibrations with amplitudes as small as 10^{-9} m can be detected. It is usually from the maximum shaking amplitude, A, of the vibrations that the so-called magnitude of the earthquake can be found. The Richter Scale is one such measure of earthquake magnitude and the most commonly-used by news reporters when describing earthquakes. It is a logarithmic scale, so that, for example, a magnitude 6 earthquake has ten times the shaking amplitude of one of magnitude 5. The energy, E, released by the earthquake can also be deduced from the shaking amplitude since $E \propto A^{3/2}$.

Milne seismometers, constrained to move in one horizontal dimension, clearly have limitations. Any horizontal vibration that has no component of velocity in the direction of the natural motion of the pendulum will hardly be detected at all and a purely vertical shaking of the ground could also escape detection. Two Milne devices placed at 90° to each other would solve the first of these two problems, whilst a seismometer with an altogether different design is needed to solve the second.

Damping the vibrations

Any disturbance of the seismometer will initiate an oscillation of the mass at its natural frequency and this additional motion needs to be minimised, so the system is heavily damped. Damping can be produced by having the boom (or part of it) move through a viscous medium producing lots of drag as it moves. However, electromagnetic damping is more common: a small aluminium plate attached to the boom sits in a strong magnetic field and any relative movement results in an opposing (damping) force due to Lenz's Law.

Predicting earthquakes

The development of increasingly accurate and sensitive seismometers is vital to gaining a deeper understanding of seismic behaviour. Many new designs of the instruments have emerged in recent years and the actual types used depend upon the specific requirement of the measurement: magnitude, frequency, type of wave, direction of wave and so on. By monitoring and measuring many earthquakes, it is possible that patterns will emerge that will enable geoscientists to make predictions about seismic activity. This currently remains one of the best hopes geoscientists have of making such predictions. However, other methods are being explored based upon geological and atmospheric changes that occur prior to the brittle fracture of the rocks. For example, one theory suggests that the great compression of the rocks that are about to rupture squeezes out naturally occurring radon gas into surrounding soil and water. Increased concentrations of radon in soil and ground water may therefore indicate an imminent quake and be used as a means of predicting earthquakes.

Whatever methods emerge in this vital area of geophysics, seismometers will continue to operate at the forefront of our study of these devastating but intriguing phenomena.

END OF ARTICLE