OCR
RECOGNISING ACHIEVEMENT

Monday 11 June 2012 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495 Field and Particle Pictures

ADVANCE NOTICE

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- Take the article away and read through it carefully. Spend some time looking up any technical terms or phrases you do not understand. You are **not** required to research further the particular topic described in the article.
- For the examination on 11 June 2012 you will be given a fresh copy of this article, together with a question paper. You will not be able to take your original copy into the examination with you.
- The values of standard physical constants will be given in the Advancing Physics Data, Formulae and Relationships booklet. Any additional data required are given in the appropriate question.

INFORMATION FOR CANDIDATES

- Questions in Section C of paper G495 Field and Particle Pictures will refer to this Advance Notice material and may give additional data related to it.
- Section C will be worth about 40 marks.
- Sections A and B of paper G495 will be worth about 60 marks.
- There will be 2 marks for quality of written communication (QWC) assessed in Sections B and C.
- This document consists of **8** pages. Any blank pages are indicated.

DC (NF/SW) 44428/4

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.

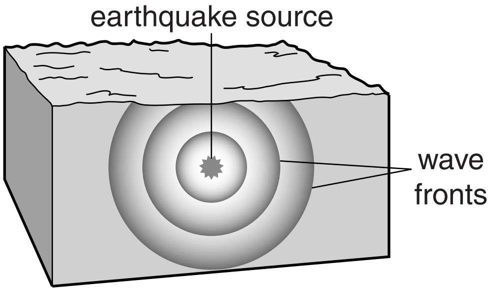


Fig. 1: seismic activity within the Earth as sources of waves

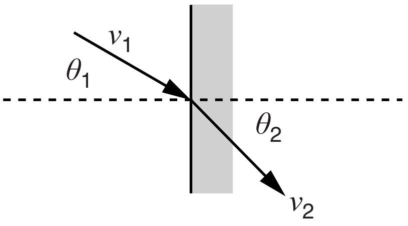
The wave motion within the Earth and at its surface is very complicated. In straightforward models, there are three main types of wave produced, some properties of which are summarised in Fig. 2. One of the factors affecting the speeds of the waves is the density of the material through which they travel. 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.

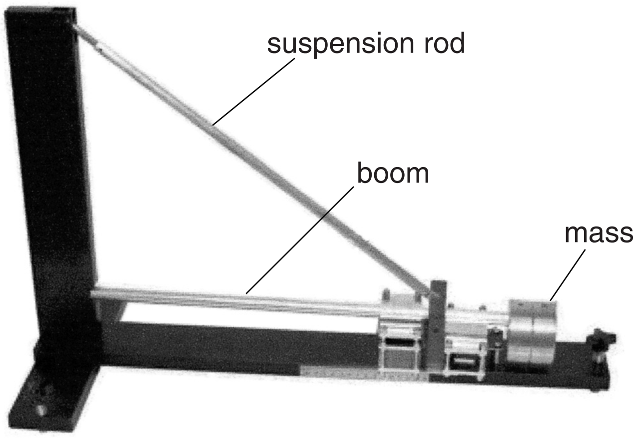


Fig. 3: photograph of a “garden-gate” (Milne) seismometer

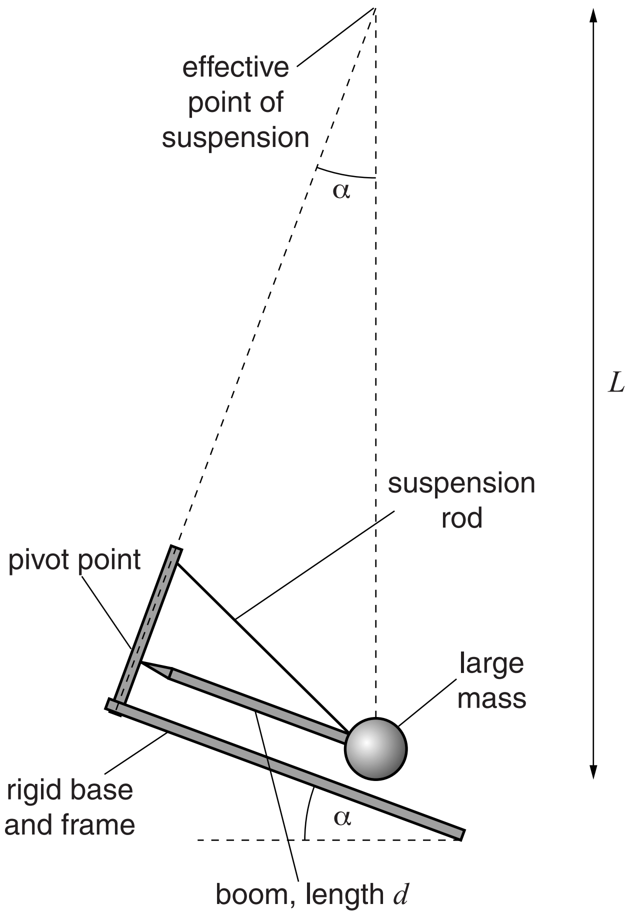


Fig. 4: design of a “garden-gate” (Milne) seismometer

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.

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