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Activity

Practice exam questions

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Use the questions below either in class or for individual work after students have read the articles in the magazine. Although the questions state the values of constants required, some of the questions require additional data – students should either make reasonable estimates of quantities or look up values using a data book or website. Students should clearly communicate any assumptions made. Suggested outline answers to questions are provided in a separate document.

Earthquake magnitudes

1 During an earthquake, both primary (P-waves) and secondary (S-waves) are detected at a seismic monitoring station. The average speed of P-waves in the Earth's crust is v_P = 8.00 km s^{-1}.The average speed of S-waves is v_S = 4.50 km s^{-1}. The seismograph records that the P-waves arrive Δt = 180 seconds earlier than the S-waves.

a Explain the difference between longitudinal (P-waves) and transverse (S-waves) in terms of particle motion relative to wave propagation.

b Using the data provided, calculate the distance d of the seismic station from the earthquake's epicenter.

Hint:

$$d = v_P t_P = v_S t_S$$
$$\Delta t = t_S - t_P$$

c A dominant P-wave frequency recorded is f = 2.00 Hz. Calculate the wavelength of the P-wave in the crust.

$$\lambda_P = \frac{v_P}{f}$$

d S-waves are not detected beyond the Earth's liquid outer core. Explain why transverse waves cannot propagate through liquids, whereas longitudinal waves can.

2 Seismologists use seismographs to measure earthquake waves. The Richter magnitude M of an earthquake can be calculated using:

$$M = \log_{10} A_{\max} + 2.56 \log_{10} \Delta - 5.12$$

where $A_{\max}$ is the maximum amplitude of the seismic wave (in μm) and Δ is the distance from the seismograph to the epicentre (in km).

a A seismograph records a maximum amplitude of 200 μm for a P-wave. The distance to the epicentre is 100 km.

i. Calculate the Richter magnitude of this earthquake.

ii Explain why the logarithmic scale is used rather than a linear scale when comparing earthquake magnitudes.

b Another earthquake produces a maximum amplitude of 2000 μm at the same distance.

i Calculate the Richter magnitude for this second earthquake.

ii Compare the destructive potential of the two earthquakes, given that each unit increase in magnitude corresponds to roughly 30 times more energy release.

c Discuss how both frequency and amplitude of seismic waves affect the damage caused by earthquakes, and why amplitude is the key parameter in the Richter scale formula.

Detecting gravitational waves

1 Gravitational waves are a prediction of Einstein's general relativity. Accelerating masses produce gravitational waves, just as accelerating electrical charges produce electromagnetic waves. Because gravity is such a weak force compared with electrical forces, gravitational waves are very difficult to detect. The interference of laser light is used to measure the tiny effects of gravitational waves.

a Explain why accelerating masses are required to produce gravitational waves, drawing an analogy with electromagnetic waves.

b A laser interferometer has two perpendicular arms, each of length 4.00 km. A passing gravitational wave changes the length of one arm by 1.00×10^{-18} m relative to the other. Calculate the fractional change in length of the arm.

c The interferometer uses laser light of wavelength 1064 nm. Calculate the phase difference introduced between the two beams due to the gravitational wave.

d Explain why detecting gravitational waves requires extremely sensitive instruments and suggest one method used to reduce noise in such experiments.

2 Gravitational waves are ripples in spacetime produced by accelerating masses, analogous to electromagnetic waves produced by accelerating charges. Because gravity is much weaker than electromagnetism, detecting gravitational waves requires extremely sensitive instruments such as laser interferometers.

A laser interferometer has perpendicular arms, each of length 3.00 km. A passing gravitational wave changes the relative arm length by 5.0×10^{-19} m.

a Calculate the fractional change in length of the interferometer arm.

b The interferometer uses laser light of wavelength 1550 nm. Calculate the phase difference introduced between the two beams due to the gravitational wave.

c Compare this fractional change with the fractional change in gravitational force between two 2.00 kg masses separated by 0.500 m, if one mass is displaced by 2.0×10^{-17} m.

Use:

$$F = \frac{Gm^2}{r^2}$$

with $G = 6.67 \times 10^{-11}$ m N m^2 kg^{-2}

d Comment on why detecting gravitational waves is far more challenging than measuring small changes in gravitational force between laboratory masses.

Hydrogen: a potential fuel of the future

1 A hydrogen fuel cell supplies a constant current of 4.00 A at a potential difference of 9.00 V. The cell operates for 15.0 minutes.

a Calculate the total charge that flows through the external circuit.

b Calculate the total electrical energy delivered by the fuel cell.

c If each mole of hydrogen releases 96.5 kC of charge, calculate the number of moles of hydrogen consumed during this time.

d Given that the molar mass of hydrogen is 2.00 g mol^{-1}, calculate the mass of hydrogen consumed.

2 A hydrogen fuel cell is used to power an electric motor. The cell provides a steady current of 8.00 A at a potential difference of 12.0 V. The motor runs continuously for 30.0 minutes.

The overall efficiency of the fuel cell is 65.0%, meaning only 65.0% of the chemical energy released is converted into useful electrical energy.

The charge released per mole of hydrogen is 96.5 kC mol^{-1}, and the molar mass of hydrogen is 2.00 g mol^{-1}.

a Calculate the total electrical energy delivered to the motor during the 30.0 minutes.

b Calculate the total chemical energy released by the hydrogen during this time.

c Determine the number of moles of hydrogen consumed.

d Calculate the mass of hydrogen consumed.

e If the motor requires a mechanical power output of 80.0 W, determine whether the fuel cell can supply this demand, and justify your answer.