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1. A bronze helmet carries a crest of horsehair fixed along its top. It is claimed that the crest was not only decorative: it also reduced the force on the head of the wearer when the helmet was struck from above.

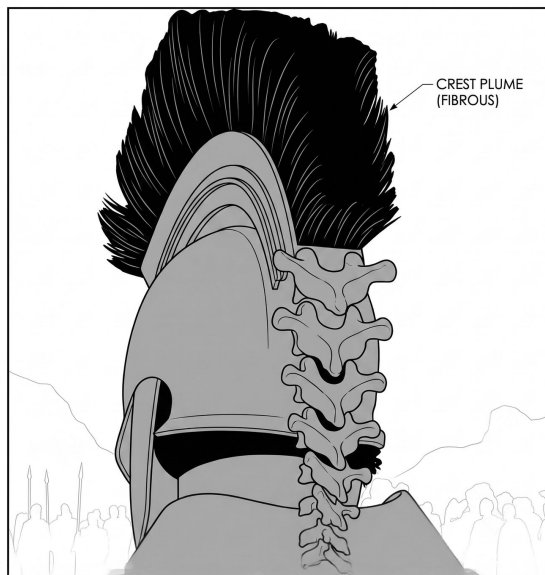


Figure 1 shows a wooden club striking the top of the crest. The club moves vertically downwards immediately before the impact and vertically upwards immediately after it.

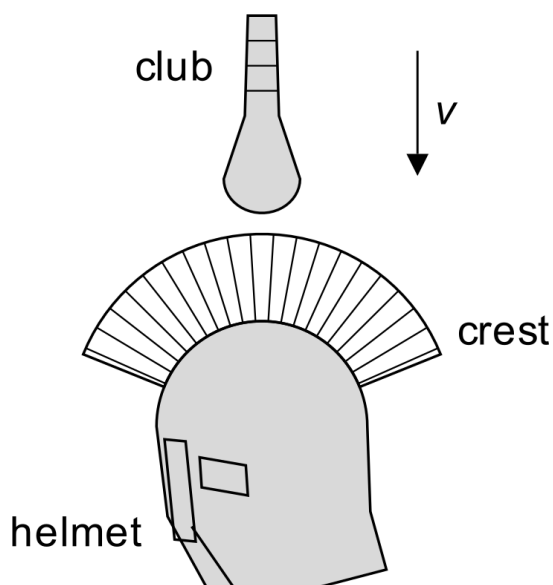


Figure 1

- (a) State, in terms of momentum, what is meant by the **impulse** of a force. [1]

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- (b) Explain how the crest reduces the maximum force exerted on the head of the wearer. [3]

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Figure 2 shows how the force exerted on the crest by the club varies with time during the impact.

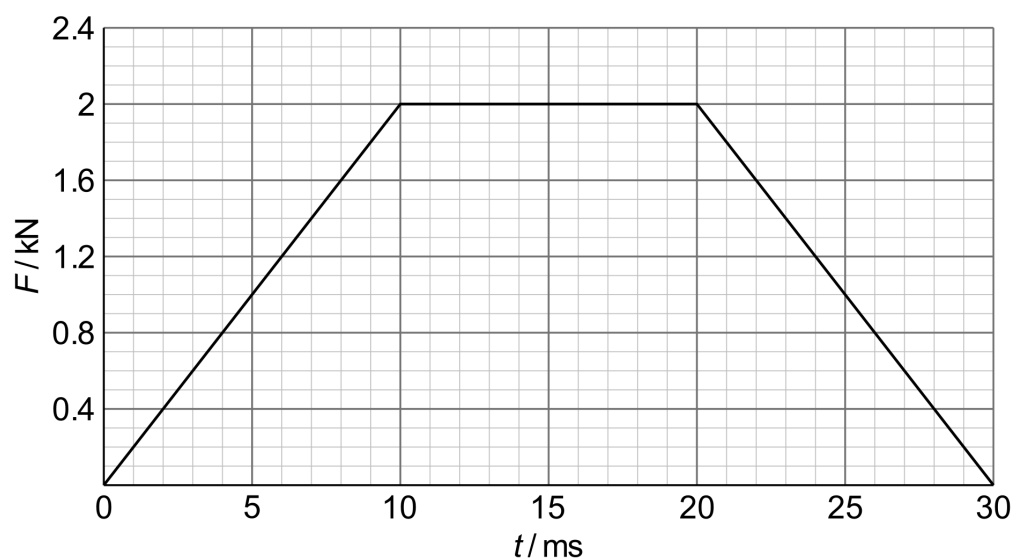


Figure 2

- (c) Show that the magnitude of the impulse delivered to the crest is about 40 N s. [2]

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- (d) The club has a mass of 2.5 kg and is moving downwards at 14 m s^{-1} immediately before the impact.
Calculate the speed of the club immediately after the impact. [2]

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- (e) The crest is now removed. The same club strikes the bare bronze helmet and delivers the same impulse in a contact time of 5.0 ms.
Determine the ratio
average force on the bare helmet $\div$ average force on the crested helmet. [2]

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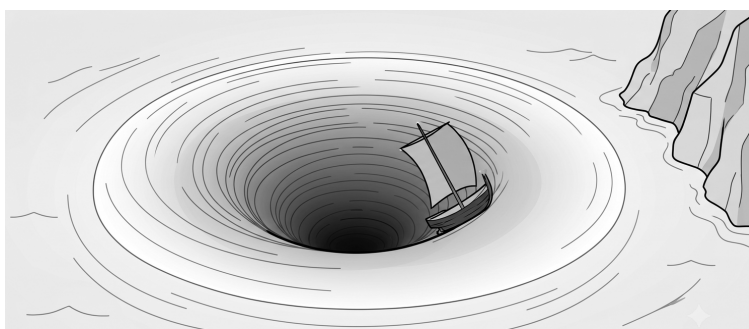
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2. A ship is caught on the wall of a whirlpool. It travels at a constant speed in a horizontal circle around the axis of the whirlpool, as shown in **Figure 3**.



The surface of the water is smooth. The buoyancy force on the ship acts at right angles to the water surface.

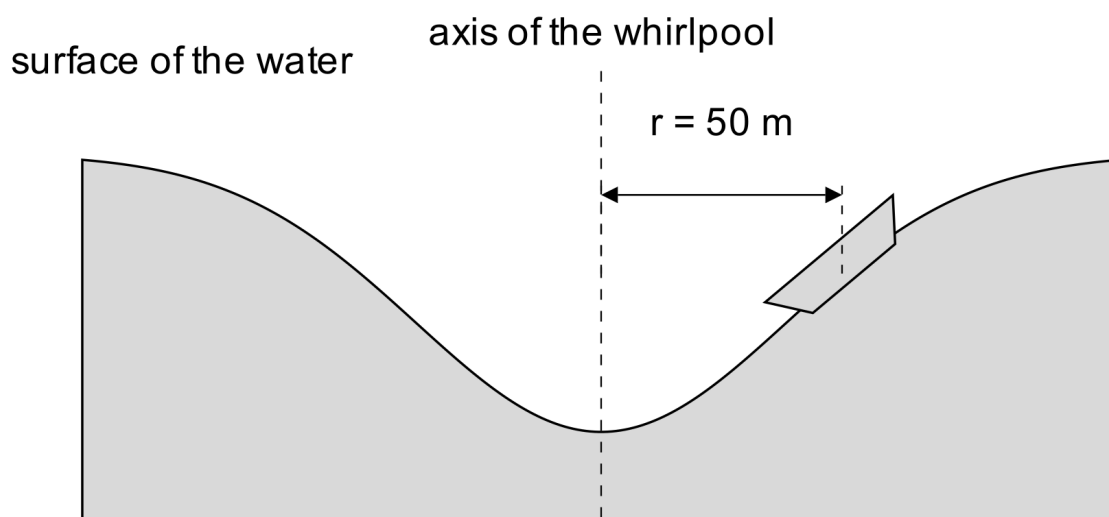


Figure 3

- (a) State the direction of the resultant force acting on the ship. [1]

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Figure 4 is an enlarged view of the ship, showing the buoyancy force and the angle θ .

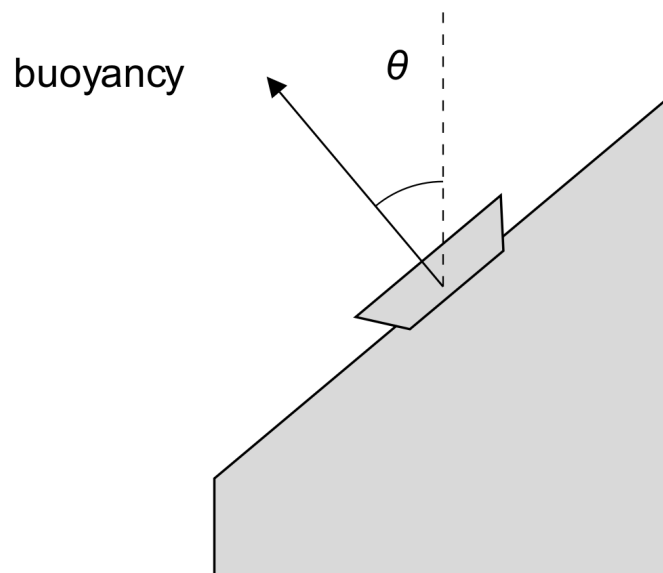


Figure 4

- (b) Draw, **in the box below**, a labelled free-body diagram of the ship. [2]

- (c) Show that the magnitude of the resultant force on the ship is $mg \tan \theta$, where m is the mass of the ship. [2]

(d) For this ship $\theta = 40^\circ$.

Show that the speed of the ship is about 20 m s^{-1} .

[3]

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(e) Calculate the time taken for the ship to complete one circuit of the whirlpool.

[2]

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The ship escapes the whirlpool. A sailor of mass 70 kg falls from the rigging and is left hanging from a rope of length 8.0 m attached to the top of the mast. He swings backwards and forwards through the vertical. His maximum angular displacement from the vertical is 12° , as shown in **Figure 5**.

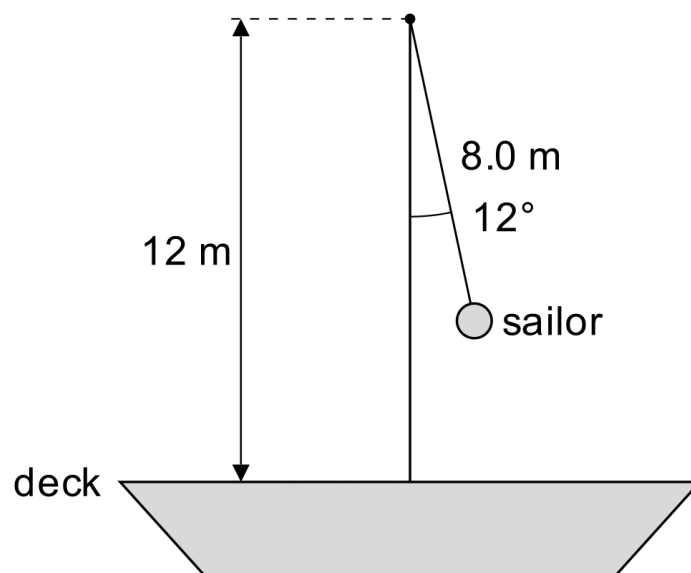


Figure 5

- (f) State the condition that must be satisfied by the acceleration of the sailor for his motion to be simple harmonic. [1]

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- (g) Draw, **in the box below**, a labelled free-body diagram of the sailor at the instant of maximum angular displacement. [2]

(h) Calculate the period of the swing. [2]

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(i) Determine the maximum speed of the sailor. [2]

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(j) The top of the mast is 12 m above the deck.
Determine the magnitude of the torque exerted on the mast, about its base, at the instant of maximum angular displacement. [3]

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3. The polished bronze of a warrior's breastplate is modelled as a metal surface that shows the photoelectric effect.



Figure 3.1: Annotated Diagram of a Spartan Hoplite's Panoply and Formation Positioning (c. 480 BCE).

Light of a single frequency f is shone onto the breastplate and the maximum kinetic energy E of the emitted electrons is measured. **Figure 6** shows the result of repeating the measurement for a range of frequencies.

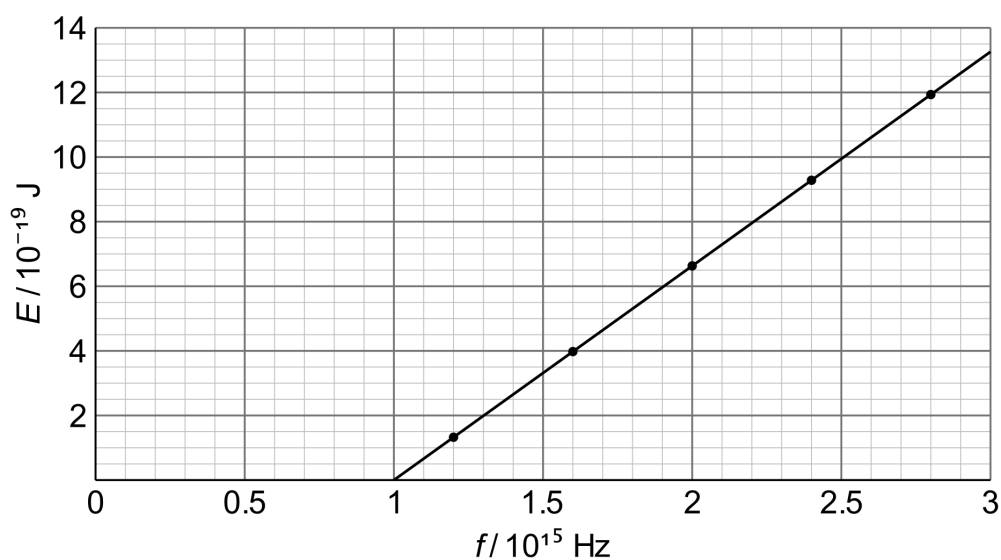


Figure 6

- (a) State what is meant by the **work function** of a metal.

[1]

(b) Determine, using **Figure 6**, the work function of the bronze in eV. [3]

(c) Determine, using **Figure 6**, a value for the Planck constant. [2]

(d) Light of wavelength 75 nm is now shone onto the breastplate.
Calculate the maximum kinetic energy of the emitted electrons. [2]

(e) The intensity of this light is doubled.

State and explain the effect of this on the maximum kinetic energy of the emitted electrons. **[2]**

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4. A navigator fixes his course on a bright star. He records the position of the star against a background of very distant stars. Six months later he records its position again, and finds that it has shifted.

Figure 7 shows the two observations, made from the two ends of a diameter of the orbit of the Earth.

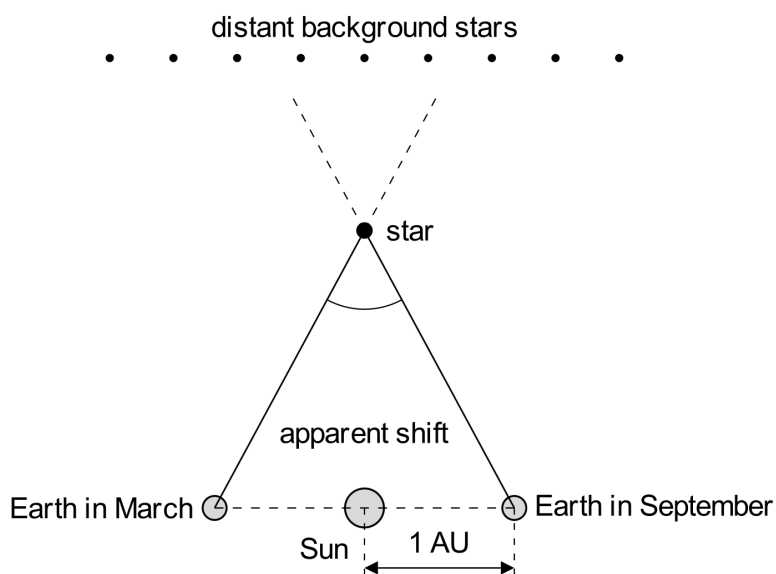


Figure 7

- (a) State what is meant by one **parsec**. [1]

- (b) Outline why the position of the star appears to shift, while the positions of the background stars do not. [2]

- (c) The total change in the apparent position of the star over the six months is 0.50 arc-seconds.

Determine the distance of the star from the Earth, in parsecs.

[2]

- (d) Show that this distance is about 1.2×10^{17} m.

[2]

- (e) A second star has a parallax angle of 0.125 arc-seconds and a luminosity twice that of the first star.

Determine the ratio

apparent brightness of the first star $\div$ apparent brightness of the second star.

[2]

- (f) Explain why the parallax method cannot be used for a star at a distance of 10^5 pc. **[2]**

5. Two ships, S_1 and S_2 , row in step so that each sends out water waves of the same wavelength, in phase with each other. The waves meet at a point P on the gate of an enemy harbour, as shown in **Figure 8**.

The wavelength of the waves is 12 m.

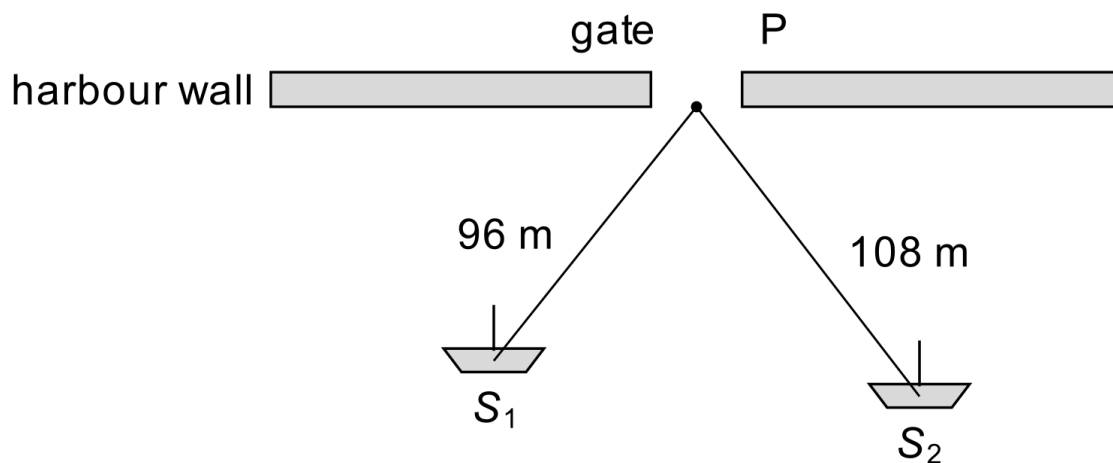


Figure 8

- (a) State the condition, in terms of path difference, for the waves to arrive at P in phase. [1]

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- (b) Deduce whether the waves arriving at P are in phase. [2]

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- (c) The waves travel at 6.0 m s^{-1} .

Calculate the time between successive waves arriving at P.

[2]

- (d) Each wave on its own would give the water at P an amplitude of 0.80 m .

State the amplitude of the water at P when both ships are rowing.

[1]

- (e) The intensity of a wave is proportional to the square of its amplitude.

Determine the ratio

intensity at P with both ships rowing $\div$ intensity at P with S_1 rowing alone.

[2]

- (f) S_2 now rows to a new position, 114 m from P.

State and explain the amplitude of the water at P.

[3]

- (g) In practice the water at P does not become completely still.

Suggest why.

[1]

6. The Sirens sing from a rock. Their song is a single note of frequency 512 Hz. A ship sails past the rock along a straight course at constant speed, passing through the positions A, B and C shown in **Figure 9**. At B the ship is level with the rock.

The speed of sound in air is 340 m s^{-1} .

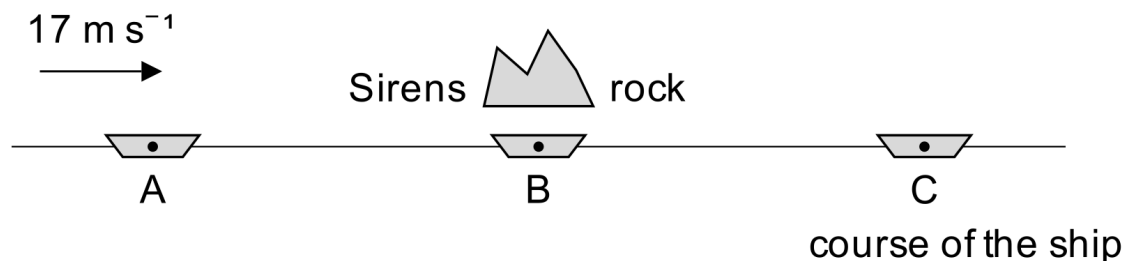


Figure 9

- (a) State what is meant by the **Doppler effect**. **[1]**

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- (b) Calculate the frequency of the song heard by the sailors at A. **[2]**

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- (c) Determine the difference between the frequency heard at A and the frequency heard at C. **[2]**

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- (d) State the frequency heard by the sailors at B, and explain your answer. [3]

- (e) Sketch, on the axes below, how the frequency heard by the sailors varies with time as the ship sails from A to C. [2]

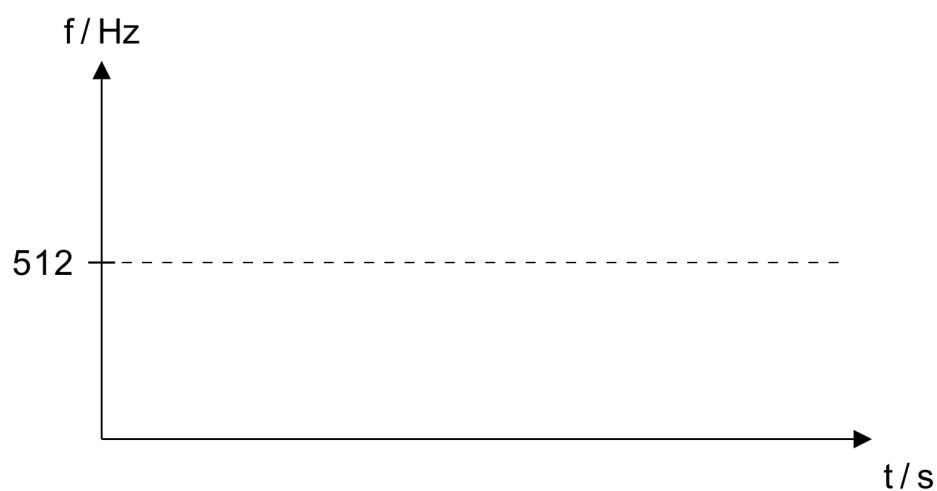


Figure 10

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