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.

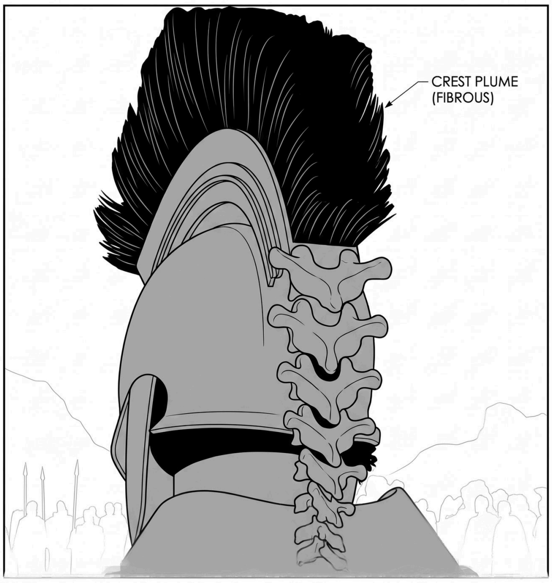

Figure 1 shows a wooden club striking the top of the crest. The club moves vertically downwards immediately before the impact and vertically upwards immediately after it.

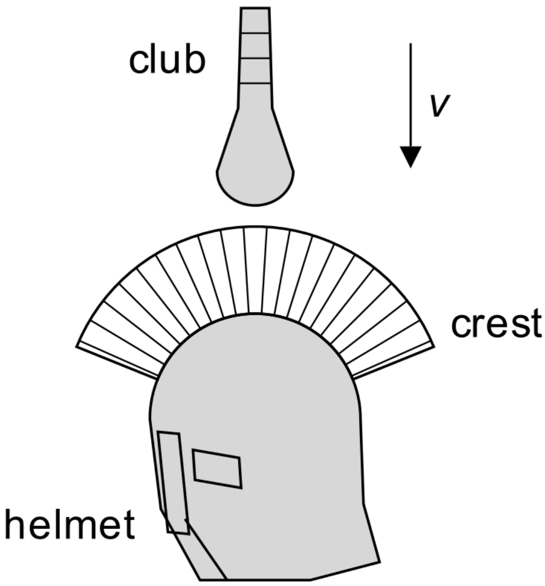

Figure 1

(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.

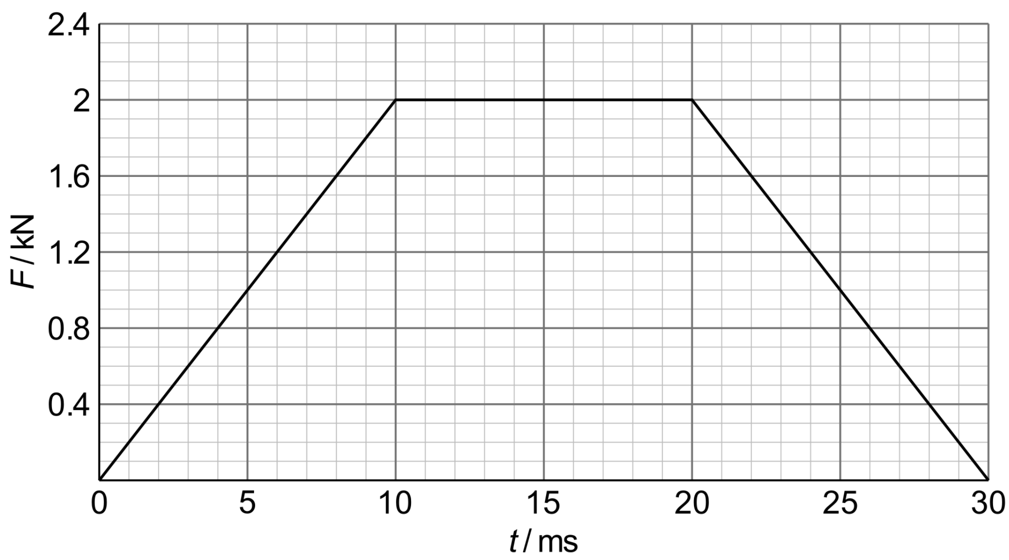


Figure 2

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

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

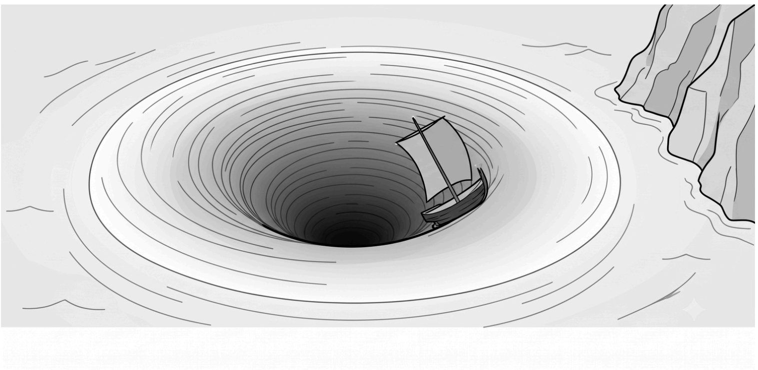
Calculate the speed of the club immediately after the impact. **[2]**

(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 ÷ average force on the crested helmet. **[2]**

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.

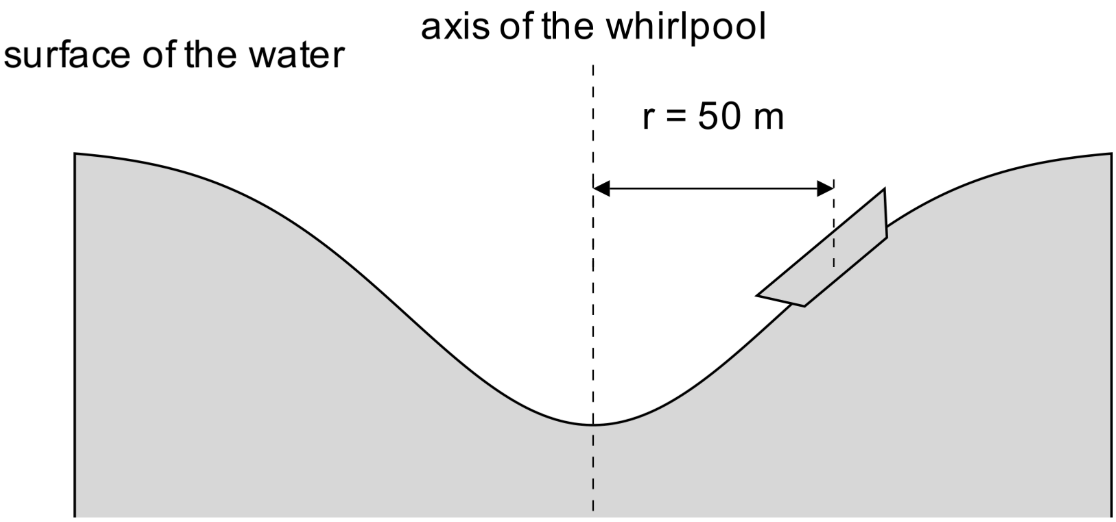


Figure 3

(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.

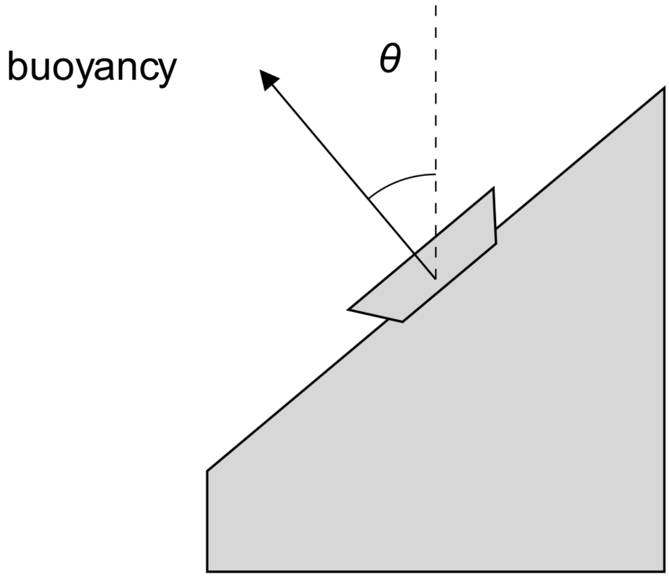

Figure 4

(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 $\theta = 40°$.

Show that the speed of the ship is about 20 m s^{-1}. **[3]**

(e) Calculate the time taken for the ship to complete one circuit of the whirlpool. **[2]**

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**.

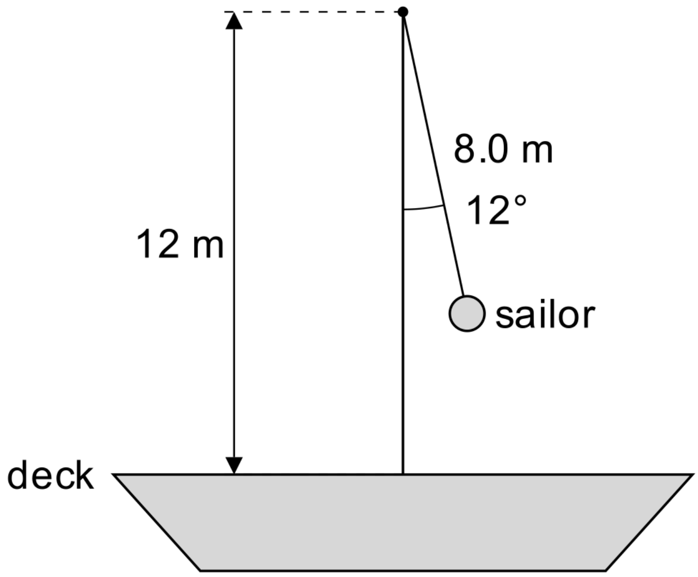

Figure 5

(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]**

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

3. 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 6 shows the two observations, made from the two ends of a diameter of the orbit of the Earth.

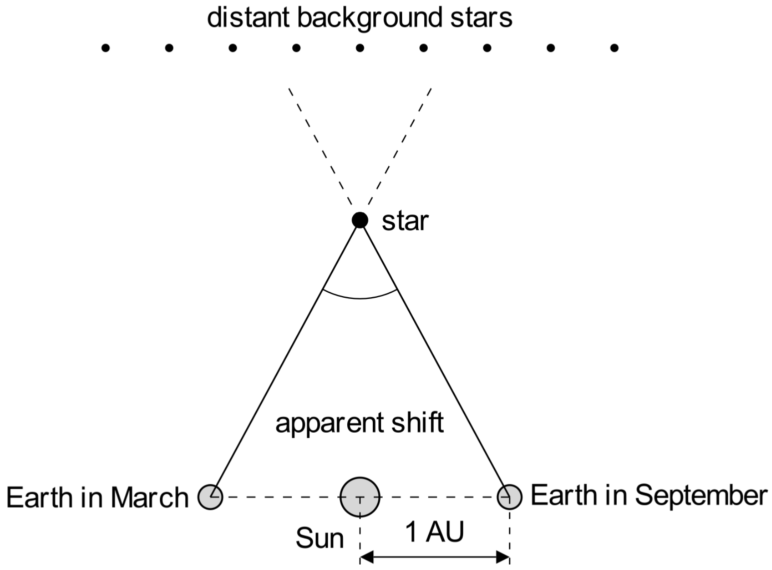

Figure 6

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

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

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(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 ÷ 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]**

4. 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 7**.

The wavelength of the waves is 12 m.

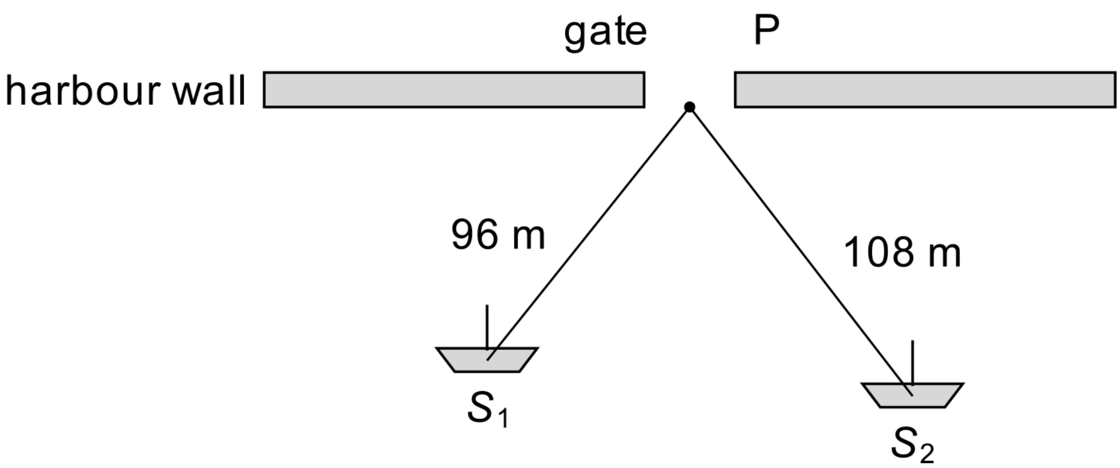

Figure 7

(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 ÷ 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]**

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