Physics 3AB

Particles, Waves and Quanta Test 2013

Name: SOLUTIONS	Mark: / 60 = %

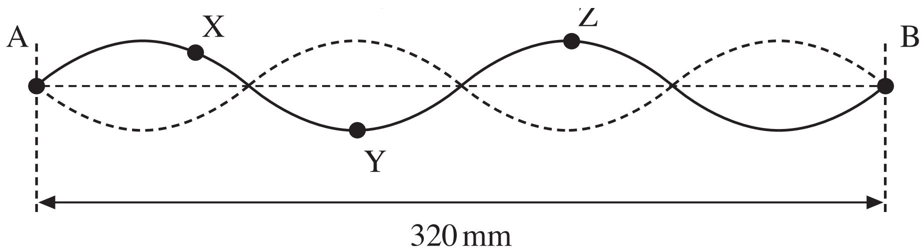
Time Allowed: **50 minutes**

Notes to Students:

- You must include **all** working to be awarded full marks for a question.
- Marks will be deducted for incorrect or absent units and answers stated to an incorrect number of significant figures.
- **No** graphics calculators are permitted – scientific calculators only.

Question 1 **(11 marks)**

When a note is played on a violin, the sound it produces consists of the fundamental and many overtones. The diagram below shows the shape of the string for a stationary wave that corresponds to one of these overtones.



The positions of maximum and zero displacement for one overtone are shown. Points A and B are fixed. Points X, Y and Z are points on the string.

(a) State the phase relationship between:

(2 marks)

i. A and Y: 90° or 270° out of phase

ii. Y and Z: 180° out of phase

The frequency of this overtone is 780 Hz.

(b) Determine the speed of a wave on this string.

(3 marks)

$\lambda = L / 2$

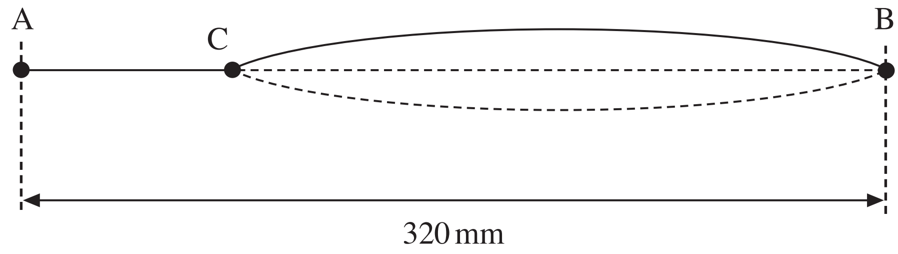
$\lambda = 0.320 / 2 = 0.160$ m (1)

$v = f \lambda$ (1)

$v = 780 \times 0.160 = 124.8$

$v = 125 \text{ ms}^{-1}$ (1)

The violinist presses on the string at C to shorten the part of the string that vibrates. The diagram below shows the string between C and B vibrating in its fundamental mode. The length of the whole string is 320 mm and the distance between C and B is 240 mm.



(c) State the name given to the point on the wave midway between C and B.

(1 mark)

Antinode

(d) Calculate the wavelength of this stationary wave.

(2 marks)

$\lambda = 2L$ (1)
$\lambda = 2 \times 240 = 480$ mm $= 0.480$ m (1)

(e) Calculate the frequency of this fundamental mode, using the wave speed calculated in (c). If you could not calculate a value use 115 ms^{-1}.

(3 marks)

$v = f\lambda$ (1)
$f = v / \lambda = 125 / 0.48$ (1)
$f = 260$ Hz (1)

If 115 ms^{-1} used: f = 240 Hz

Question 2 **(9 marks)**

When free electrons collide with atoms in their *ground state*, the atoms can be excited or ionised.

(a) State what is meant by ground state.

(1 mark)

When electrons (or atoms) are in their minimum energy state

OR

When the atom is in a stable state and has no excited electrons

(b) Explain the difference between excitation and ionisation.

(2 marks)

- Excitation occurs when an electron receives the correct amount of energy to raise it to a higher energy level.
- Ionisation occurs when an electron receives enough energy to completely leave the atom.

(c) An atom can also become excited by the absorption of photons. Explain why only photons of certain frequencies cause excitation in a particular atom.

(3 marks)

- Electrons occupy discrete/exact energy levels and they need to absorb the exact amount of energy to move to a higher level.
- The electrons receive the energy from the incoming photons.
- Photons need to have certain frequency to provide this energy ($E = hf$)

(d) The ionisation energy of hydrogen is 13.6 eV. Calculate the minimum frequency necessary for a photon to cause the ionisation of a hydrogen atom.

(3 marks)

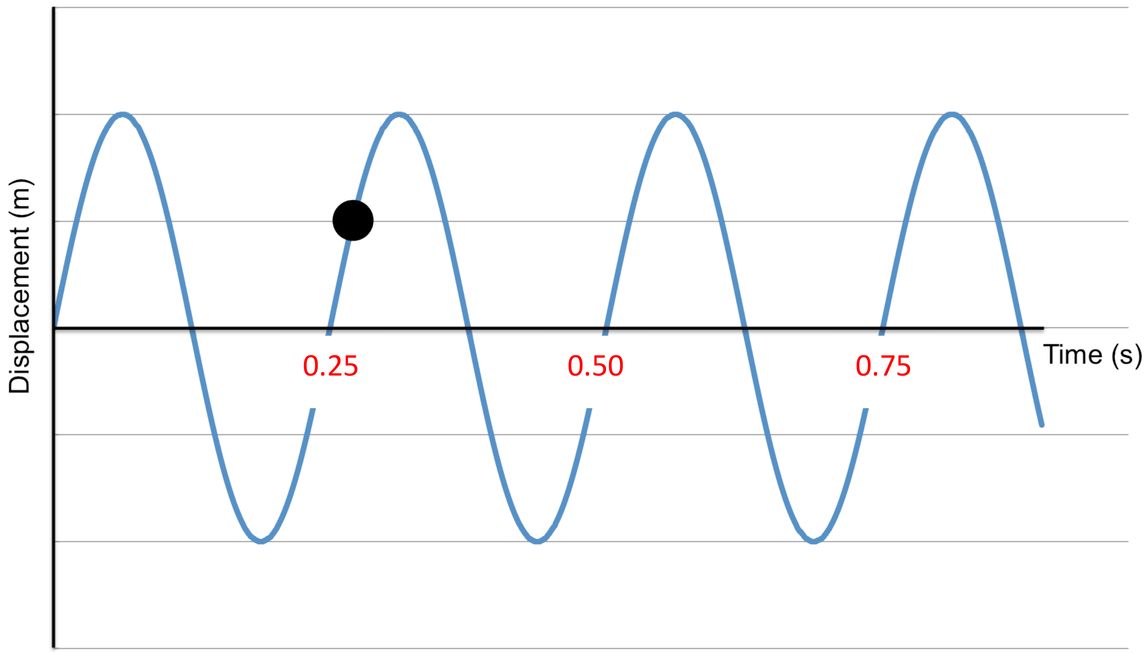
13.6 eV = 13.6 x 1.6 x 10^{-19} = 2.18 x 10^{-16} J (1)

E = hf (1)

f = E / h = 2.18 x 10^{-16} / 6.63 x 10^{-34} = 3.28 x 10^{15} Hz (1)

Question 3 **(2 marks)**

A graphical representation of the motion of a wave is shown below. The period of the wave is 0.250 s.



(a) Add a scale to the x axis.

(1 mark)

(b) State the direction of motion of the particle at the time shown on the graph.

(1 mark)

Upwards

Question 4 **(5 marks)**

A Sound Navigation And Ranging (sonar) vessel uses reflected sound waves to measure the depths of water. A pulse of sound of frequency 20.0 kHz is produced and directed down and the reflection is detected 5.77 seconds later.

(a) Calculate the depth of the ocean at that point. The speed of sound in water is 1.48 km s^{-1}.

(3 marks)

v = s / t (1)

s = vt = 1480 x (5.77 / 2) (1)

s = 4.27 x 10^3 m (1)

(b) If the water temperature were increased, what would happen to the speed of sound? Explain your reasoning.

(2 marks)

- Speed of sound would increase.
- Increased temperature means the water particles have more kinetic energy so vibrations are transferred more quickly.

Question 5 **(8 marks)**

A pair of sound technicians are preparing a venue for a concert.

To test the speakers they use a signal generator to produce a monotone. The technicians realise they have done something wrong when they hear a throbbing with a frequency of approximately 6.00 Hz. One speaker is emitting sound at the correct frequency of 628 Hz, but when its frequency is decreased the rate of the throbbing sound increases.

(a) What frequency is the second speaker emitting?

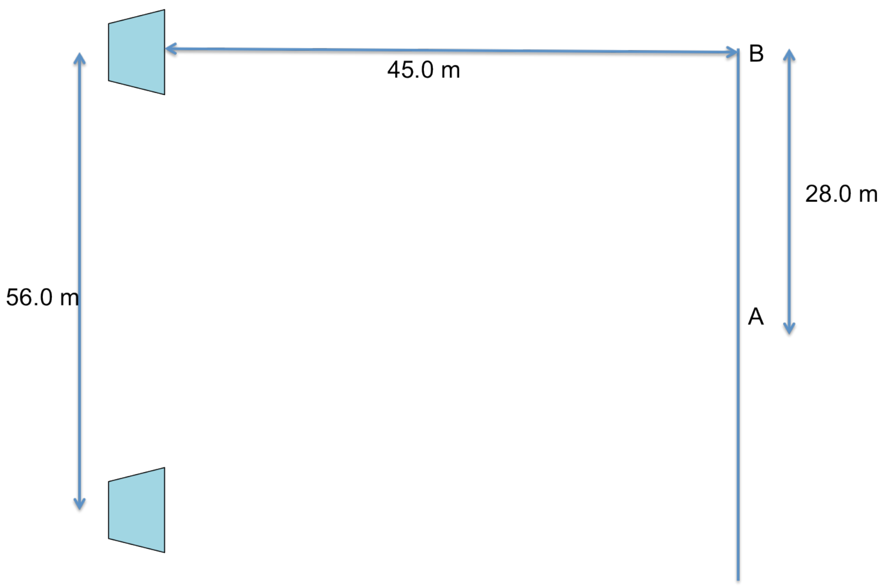
(3 marks)

$f_{beat} = |f_1 - f_2| = 6$ Hz (1)

If f_{beat} increases the difference between them has increased so 628 Hz is the lower frequency. (Appropriate working/justification to earn mark) (1)

$f_2 = f_1 + 6 = 634$ Hz (1)

The technicians fix the problem and both speakers are now emitting the same frequency, which is different to the previous ones. They arrange the speakers as shown in the diagram below. Assume the temperature on the day is 25.0°C.



(b) What will a technician hear if he stands at point A?

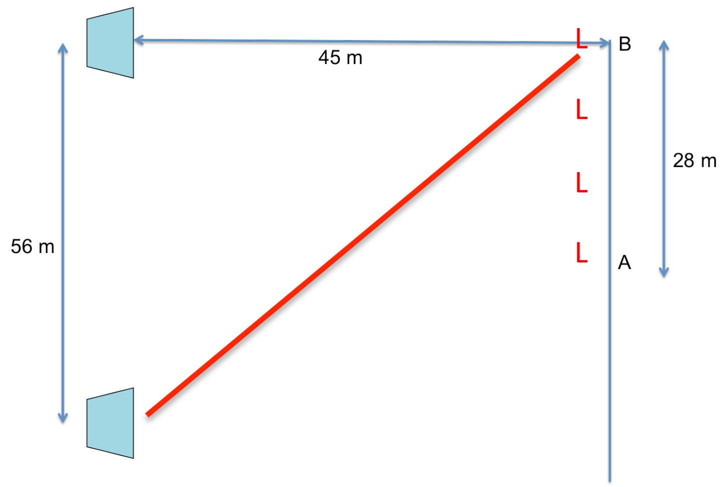
(1 mark)

Loud sound

As one of the technicians walks from point A to point B he hears the sound level increase 3 times and stops on this third increase in sound.

(b) What is the frequency being emitted from the speakers?

(4 marks)



Using Pythagoras theorem: $\sqrt{(56^2 + 45^2)} = 71.8$ m (1)

Path difference = 71.8 – 45 = 26.8 m

Path difference = 3 λ (1)

λ = 26.8 / 3 = 8.93 m

v = f λ (1)

f = v / λ = 346 / 8.93

f = 38.7 Hz (1)

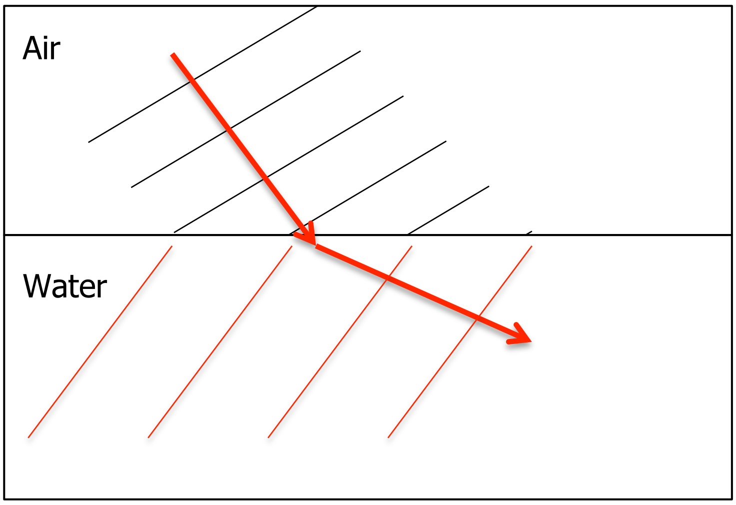
Question 6 **(5 marks)**

Sound waves are shown travelling from air (at 25.0°C) to water, in the diagram below.

(a) Complete the wavefront diagram, showing the wave fronts in the water.

(2 marks)

- 1 mark for arrows
- Lines must be straight, evenly spaced and more spaced than in air



(b) The source of the sound waves in air oscillates once every 4.00 s. Determine the wavelength of the sound waves.

(3 marks)

T = 4 s

f = 1/T = 0.25 Hz (1)

v = f λ (1)

λ = v / f = 346 / 0.25

λ = 1.38 x 10^3 m (1)

Question 8 **(7 marks)**

Hadrons are a group of particles composed of quarks. Hadrons can either be baryons or mesons.

(a) What property defines a hadron?

(1 mark)

Experiences/interacts with the strong force

(b) State one similarity and one difference between a particle and its antiparticle.

(2 marks)

- Similarity: Same mass / lifetime / spin
- Difference: Charge *(can only state spin if a neutral particle is specified)*

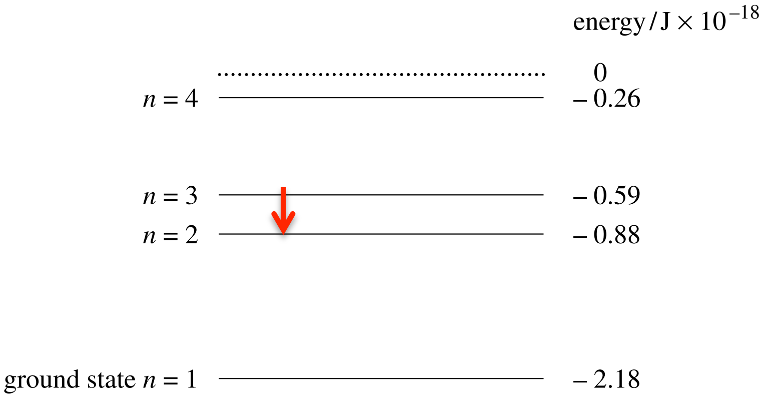
(c) Complete the table below.

(4 marks)

	Charge (C)	Quark structure
Neutron	0	udd
Antiproton	-1e	$\bar{u}\bar{u}\bar{d}$

Question 9 **(4 marks)**

The lowest energy levels of a mercury atom are shown in the diagram below. The diagram is not to scale.



(a) Calculate the frequency of an emitted photon due to the transition level $n = 4$ to level $n = 3$.

(3 marks)

$0.59 – 0.26 = 0.33 \times 10^{-18}$ J (1)

E = hf (1)

$f = E / h = 0.33 \times 10^{-18} / 6.63 \times 10^{-34}$

$f = 4.98 \times 10^{14}$ Hz (1)

(5.0×10^{14} Hz is acceptable as question information is to 2 sf)

(b) Draw an arrow on the diagram above to show a transition which emits a photon of a longer wavelength than that emitted in the transition from level $n = 4$ to level $n = 3$.

(1 mark)

- Arrow from level n = 3 to level n = 2
- Arrow must be going the correct way

Question 10 **(9 marks)**

In an experiment, electrons are accelerated through a potential difference of 120 kV. The electrons collide with a tungsten target and radiation is detected.

(a) Calculate the maximum amount of energy of each electron in joules.

(2 marks)

$(120 \times 10^{3})(1.6 \times 10^{-19}) = 1.92 \times 10^{-14}$ J

(1) (1)

(b) Calculate the minimum wavelength of the radiation emitted.

(3 marks)

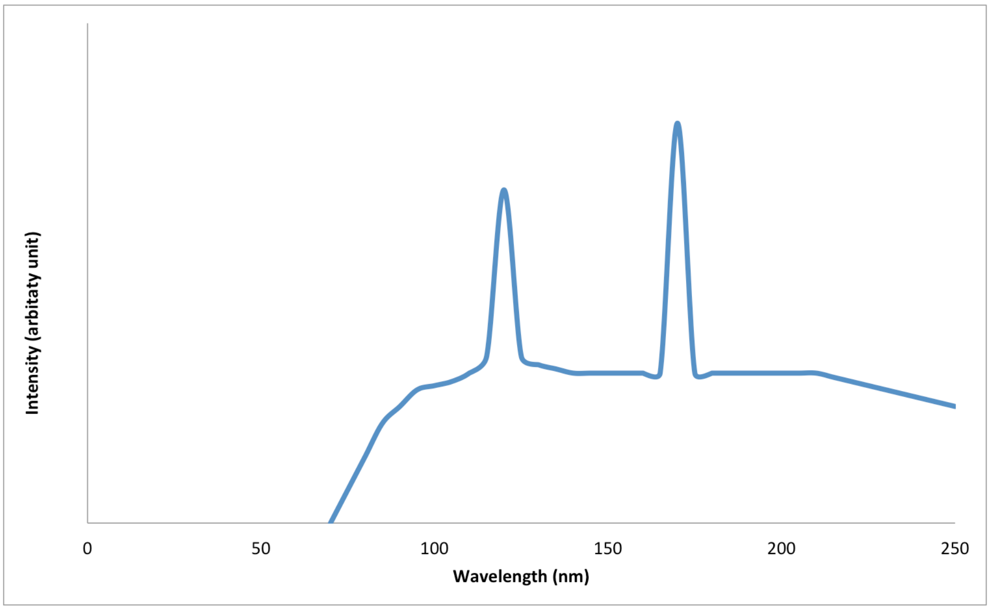
E = hf   v = f λ   or   E = hv / λ (1)

$1.92 \times 10^{-14} = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda$ (1)

$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / 1.92 \times 10^{-14} = 1.04 \times 10^{-11}$ m

(1)

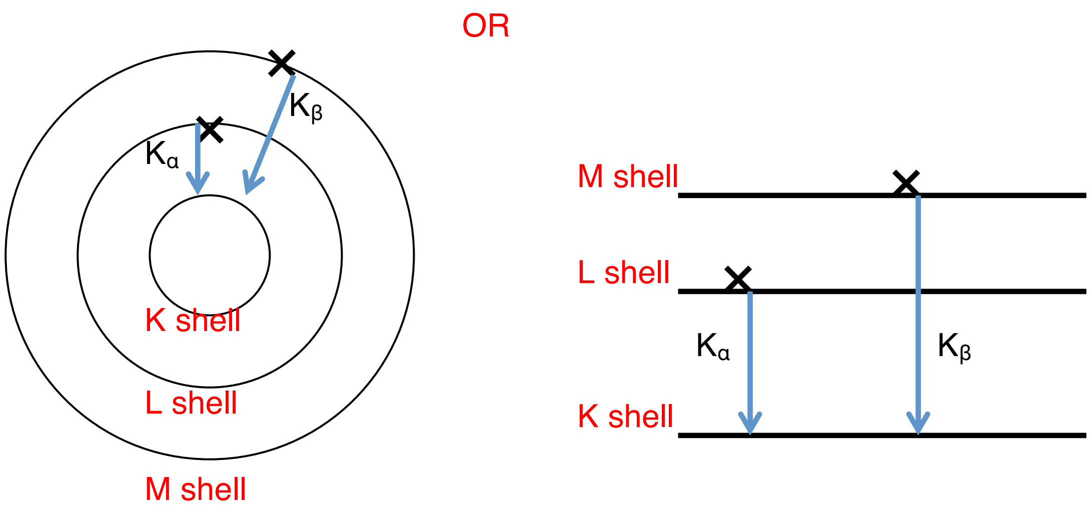
The following graph shows the spectrum of radiation produced.



(c) With the aid of an appropriate diagram, explain why the graph has two distinct peaks (**write your answer on page 13**).

(4 marks)

- If an accelerated electron passes close enough to a nucleus of a target atom it can knock an electron from the inner shell (K shell).
- Electrons from the higher shells (L and M) drop down to fill the inner shell (as the atom is now highly charged/unstable).
- The change in energy levels of the dropped electron corresponds to the frequency of an emitted photon (E = hf). The wavelength of the peaks corresponds to the frequency (v = fλ) of the photon.
- Appropriate diagram showing energy level changes, with K_α and K_β correctly labelled:



End of Test