QUESTION THREE: RESONANCE AND THE DOPPLER EFFECT (8 marks)

Assessor's use only

Speed of sound in air = 340 m s^{-1}
Acceleration due to gravity = 9.80 m s^{-2}

Consecutive resonant frequencies in a tube will occur when an extra half-wavelength of the sound fits into the tube.

(a) The depth of a well can be measured using a frequency generator. Successive resonances are observed at frequencies of 99.2 Hz and 127.5 Hz.

Calculate the depth of the well.

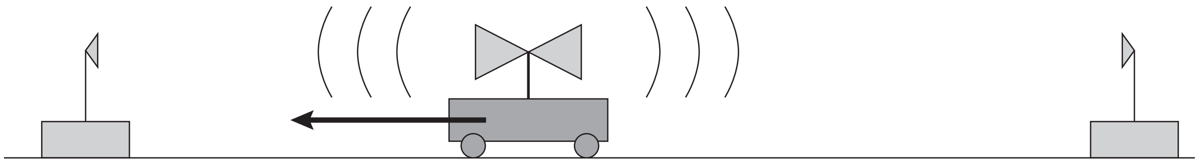
(b) On a second deeper well, a different technique is used to measure the depth. A small object that emits a constant frequency of 530 Hz is dropped down the well. The observer, at the top of the well, hears the frequency decreasing as the object drops into the well. Just before the object hits the bottom of the well the observed frequency is 500 Hz.

Calculate the depth of the well.

QUESTION FOUR: THE DOPPLER EFFECT (8 marks)

Assessor's use only

(a) A class experiment was set up to investigate the Doppler effect for sound. Two speakers facing forwards and backwards respectively, were mounted on the roof of a car and connected to a signal generator set to a frequency of 1500 Hz.



Two microphones, A and B, one placed forward of the car and the second placed to the rear of the car, were used to detect the sound of the speakers. Each microphone was connected to an instrument that measured the frequency of the received sound. With the car moving towards detector A several runs were made at different speeds. Prior to the experiment the class made a table of the expected frequency measurements, as shown below (the speed of sound was assumed to be 340 m s^{-1}).

Speed / m s^{-1}	**Predicted frequency / Hz**		**Actual frequency / Hz**	
	A Column 2	B Column 3	A Column 4	B Column 5
0	1500	1500	**1500**	
10	1545	1455	**1545**	
20	1594	1406	**1594**	

(i) The class's predictions for microphone A, calculated from a formula, are shown in column 2. Based on these results, the class write down predictions for microphone B (column 3).

In doing this, what assumption has the class made?

(ii) By using an appropriate formula, calculate the actual frequencies observed at B (column 5).

(iii) The predicted frequencies for microphone B (column 3) do not match the actual frequencies (column 5).

Explain the reason for this difference using physical arguments.

(b) Your friend Daniel and you are watching the Sun set. Daniel has been learning about the Doppler effect and he explains the colour of the sunset to you as follows, "As the Earth spins towards the East, the Sun sets in the West. As we look towards the setting Sun, we are moving away from it at the maximum speed for the day. So the light from the Sun is 'red shifted' by the Doppler effect and it is this that gives us that brilliant orange-red colour."

Using your knowledge of physics, how would you reply? You might like to acknowledge any statements he makes that are correct. But, if he is wrong on anything, how can you convince him?

Assessor's use only

(8)

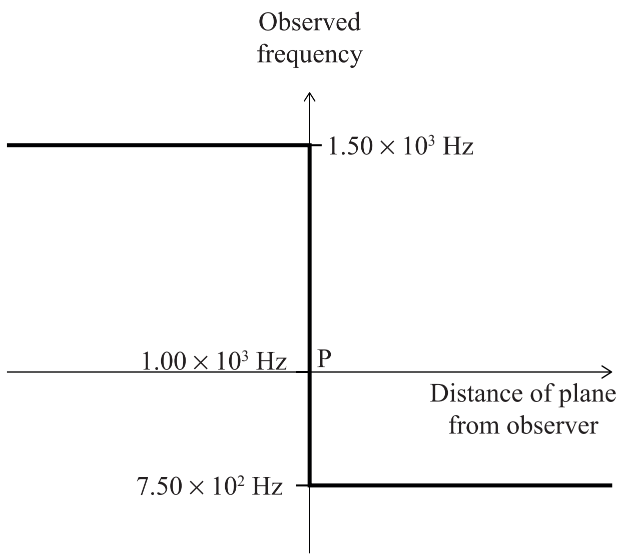
ASSESSOR'S USE ONLY

QUESTION ONE: DOPPLER DROP

Speed of sound in air = 3.40×10^2 m s^{-1}

Acceleration due to gravity = 9.81 m s^{-2}

(a) The graph shows the theoretical sound frequency of a plane flying by an observation point, P, against the distance of the plane from that observation point. The plane is emitting a sound frequency of 1.00×10^3 Hz and has a constant speed relative to the ground.



(i) Explain the physical process that causes the changes in frequency.

State any assumptions that are implied by the shape of the graph.

(ii) Show that the plane's speed is 113 m s^{-1}.

(b) The plane flies with constant speed of 113 m s^{-1} at a height of 5.00×10^2 m above an observer on the ground.

Calculate the frequency of the sound reaching the observer when the plane is seen to be directly overhead.

(c) The plane flies with a constant vertical lift-force so that it maintains a uniform height. It has an unloaded mass of 3.00×10^3 kg and is carrying a cargo pod of 1.00×10^3 kg.

When it is overhead it drops its cargo pod, but maintains the same constant vertical lift-force.

Calculate the vertical separation between the pod and the plane when the pod has been falling for 1.50 seconds.

ASSESSOR'S USE ONLY

(8)

QUESTION ONE: GENERAL RELATIVITY

ASSESSOR'S USE ONLY

Planck's constant	$= 6.63 \times 10^{-34}$ J s
Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}
Charge on the electron	$= -1.60 \times 10^{-19}$ C
Acceleration due to gravity	$= 9.81$ m s^{-2}

In an experiment carried out in 1959 at Harvard University, Einstein's General Theory of Relativity was tested. The experiment involved measuring the change in frequency of 14.0 keV gamma rays emitted from a radioactive isotope of iron-57 as the gamma rays fall through the gravitational field of the Earth. Einstein's theory predicts that the frequency of the gamma rays increases.

(a) Calculate the frequency of a 14.0 keV gamma ray.

(b) In the Harvard University experiment the gamma rays fell through a distance of 22.5 m. The change in frequency can be attributed to the change in gravitational potential energy described by the relationship $\Delta E = \frac{Eg\Delta x}{c^2}$, where E is the original energy of the 14 keV gamma ray and Δx is the distance fallen.

Show that $\frac{\Delta f}{f} = 2.45 \times 10^{-15}$.

ASSESSOR'S USE ONLY

(c) The detector in the experiment is another sample of iron-57, positioned at the base of the experiment. The gamma rays can be detected if they are absorbed by the detector. However, they will be absorbed only if their frequency has not changed.

By considering the Doppler Effect, explain an experimental technique that will allow the gamma rays to arrive at the detector with the original emitted frequency.

(d) The Doppler Effect equation for electromagnetic radiation is $f' = f\sqrt{\dfrac{1+\dfrac{v_s}{v_w}}{1-\dfrac{v_s}{v_w}}}$.

This equation can be approximated by the following expression $f' = f\left(1+\dfrac{v_s}{2v_w}\right)^2$.

Given that $\Delta f = f' - f$, use the expression to show that $\dfrac{\Delta f}{f} \approx \dfrac{v_s}{v_w}$, and explain when this would be an acceptable approximation to the Doppler Effect equation given above.

(8)

QUESTION THREE: THE DOPPLER EFFECT (8 marks)

ASSESSOR'S USE ONLY

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

Acceleration due to gravity = 9.81 m s^{-2}

(a) When the Doppler effect occurs it is known that the apparent frequency of a sound is increased as the source of the sound moves towards a stationary observer.

Explain why the frequency increase occurs.

(b) Explain qualitatively what would happen to the apparent frequency if the observer moved at constant velocity towards the moving source.

(c) Ben is on the top floor of an apartment building, and has a phone that emits a single ringing tone of 440 Hz. Unfortunately, while picking up the ringing phone, Ben drops it so that it falls off the edge of the 0.700 m high, top floor ledge he is leaning on. Some time later Ben hears a reduced frequency of 416.2 Hz. The height of each floor is 3.10 m.

Calculate the number of floors that the phone must have fallen when it emits the wave that Ben hears as a 416.2 Hz tone.

State any assumptions made.

(d) Frankie is watching Ben from the top of an identical apartment building on the other side of the street. Frankie is at the same height, but is 40.0 m away from Ben.

For the wave that Ben hears as a 416.2 Hz tone, calculate the frequency that Frankie would hear.

ASSESSOR'S USE ONLY

(8)

QUESTION FOUR: SPECTROSCOPE (8 marks)

Assessor's use only

The speed of light = 3.00×10^8 m s^{-1}

A spectroscope fitted with a diffraction grating is used to observe the spectrum of excited helium gas in a laboratory discharge tube. One first order bright line of wavelength 587.563 nm is observed at a deviation of 20.6426°.

(a) Calculate the number of lines per cm on the diffraction grating.

The spectroscope and grating are used to obtain the spectrum of a distant star, which shows a bright line blurred between 587.60 nm and 587.67 nm. This line is thought to be due to the same electron transition that produced the 587.563 nm line in the laboratory.

(b) Explain the difference between the laboratory and the stellar wavelengths.

(c) Using the equations for the Doppler effect, show that

$$\frac{v_{source}}{c} = \frac{\Delta\lambda}{\lambda}$$

where c is the speed of light, $\Delta\lambda$ is the difference between the wavelength from the star and λ, the wavelength as measured in the laboratory, and v_{source} is the speed of the star relative to the Earth.

(d) Estimate the speed of the star relative to the Earth.

State any assumptions.

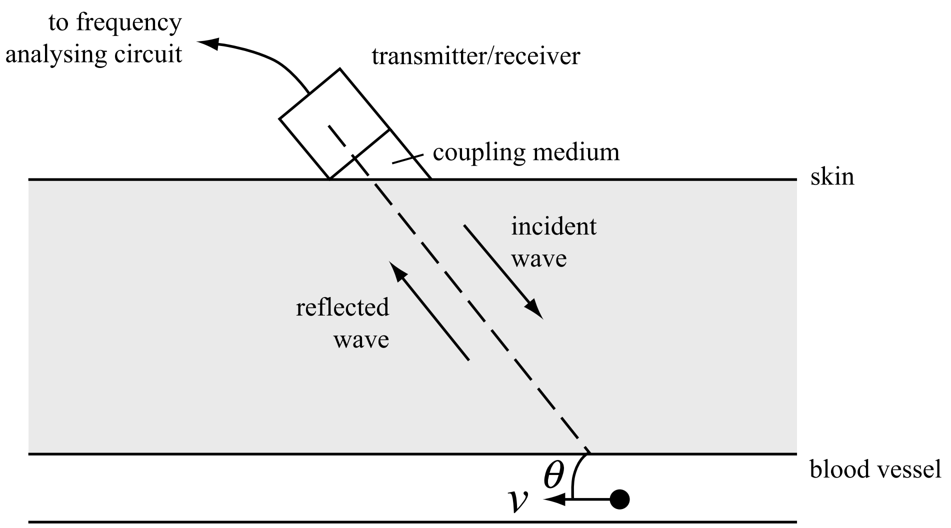
(e) Explain two possible mechanisms that cause the emission line from the star to be blurred.

Assessor's use only

(8)

QUESTION TWO: DOPPLER AND BLOOD FLOW

The velocity of blood flowing round the body can be determined using an ultrasonic transmitter/receiver and measuring the Doppler shift of the reflected wave. The diagram below shows the essential details of this process.



Reflected ultrasound from the moving blood is subsequently detected by the stationary transmitter/receiver probe shown in the diagram.

(i) Does the reflected ultrasound have a lower, higher or the same frequency as the transmitted wave? Explain.

(ii) Three students derived the following possible equations for the total frequency change recorded by the detector. Only one equation is correct.

Identify the correct equation, giving reasons to justify your choice (a derivation of the correct equation is not required).

Student 1: $\Delta f = \frac{2fv}{c}\cos\theta$

Student 2: $\Delta f = \frac{2fc}{v}\cos\theta$

Student 3: $\Delta f = \frac{2fv}{c}(1-\cos\theta)$

Where f is the transmitted frequency, Δf is the shift in frequency of the reflected waves, v is the blood velocity, c is the wave velocity and θ is the angle between the blood velocity and wave velocity.

Assessor's use only

(iii) The velocity of ultrasound in human tissue and blood is 1.5×10^3 m s^{-1} and in the application described at the beginning of Question Two, a typical frequency of 5.0 MHz is used for the transmitted ultrasound. In one particular measurement a Doppler shift of 3.1 kHz was observed with the probe inclined at an angle of 30° to the direction of the blood flow.

Calculate the speed of the blood.

speed =

(iv) Blood flow through adjacent arteries and veins is in opposite directions.

Suggest a difficulty in determining the direction of blood flow using the above technique.