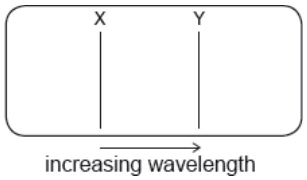
Doppler Effect *[41 marks]*

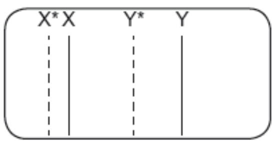
1. Two lines X and Y in the emission spectrum of hydrogen gas are measured by an observer stationary with respect to the gas sample. *[1 mark]*



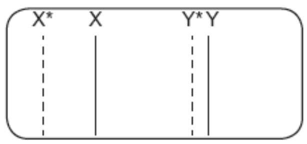
The emission spectrum is then measured by an observer moving away from the gas sample.

What are the correct shifts X* and Y* for spectral lines X and Y?

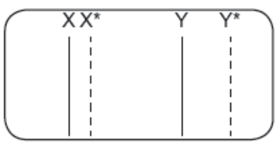
A.



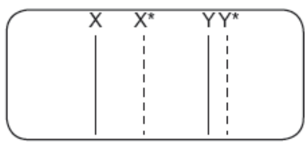
B.



C.



D.



Markscheme

C

2. A stationary sound source emits waves of wavelength λ and speed *v*. The source now moves away from a stationary observer. What are the wavelength and speed of the sound as measured by the observer? *[1 mark]*

	Wavelength	Speed
A.	longer than λ	equal to *v*
B.	longer than λ	less than *v*
C.	shorter than λ	equal to *v*
D.	shorter than λ	less than *v*

Markscheme

A

3. A train travelling in a straight line emits a sound of constant frequency *f*. An observer at rest very close to the path of the train detects a sound of continuously decreasing frequency. The train is *[1 mark]*

A. approaching the observer at constant speed.

B. approaching the observer at increasing speed.

C. moving away from the observer at constant speed.

D. moving away from the observer at increasing speed.

Markscheme

D

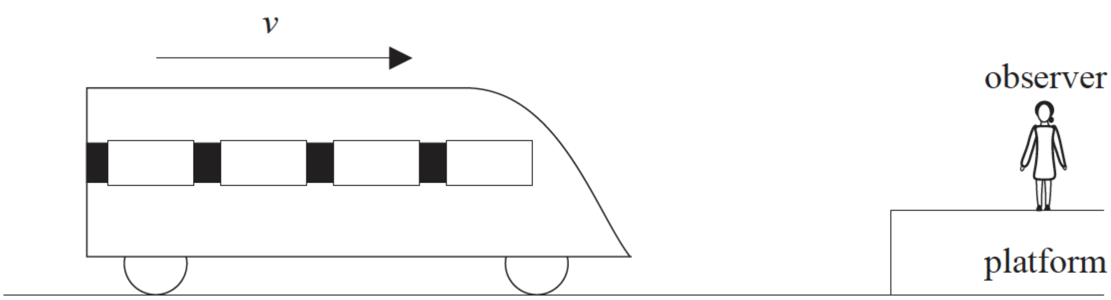
4. A source emits sound of wavelength λ_0 and wave speed v_0. A stationary observer hears the sound as the source moves away. What are the wavelength of the sound and the wave speed of the sound as measured by the stationary observer? *[1 mark]*

	Wavelength	Wave speed
A.	less than λ_0	equal to v_0
B.	greater than λ_0	equal to v_0
C.	less than λ_0	less than v_0
D.	greater than λ_0	less than v_0

Markscheme

B

5. The diagram shows a train travelling in a straight line at constant speed *v*, as it approaches the platform of a station. *[1 mark]*



The whistle of the engine is emitting a sound of constant frequency. Which of the following is **not** true for the sound of the whistle heard by an observer on the platform?

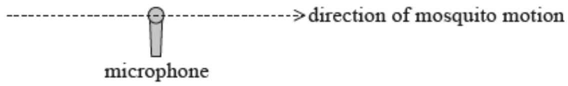
A. A sudden change in frequency of the sound as the train passes the observer.
B. A sound of constant frequency as the train approaches the observer.
C. A sound of increasing frequency as the train approaches the observer and of decreasing frequency after the train has passed the observer.
D. A sound of constant frequency after the train has passed the observer.

Markscheme

C

This question is about the Doppler effect.

Georgia carries out an experiment to measure the speed of mosquitoes. She sets up a microphone to record the sounds of passing mosquitoes.



One mosquito is moving in a straight line with constant speed and passes very close to the microphone as seen in the diagram. The mosquito produces a sound of constant frequency.

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

6a. The maximum frequency recorded is 751 Hz and the minimum frequency recorded is 749 Hz. Explain this observation. *[2 marks]*

Markscheme

as the mosquito approaches the wavelength perceived by Georgia is shorter and therefore the perceived frequency is higher;

as the mosquito is moving away, the wavelength perceived is longer than the emitted and therefore the perceived frequency is lower;

due to the Doppler effect;

6b. Determine the speed of the mosquito. *[3 marks]*

Markscheme

approaching $751 = f \times \frac{340}{340-u}$;

moving away $749 = f \times \frac{340}{340+u}$;

to produce $u = 0.45\ \mathrm{m\,s^{-1}}$;

or

emitted frequency is $\frac{751+749}{2} = 750\ \mathrm{Hz}$;

applying the Doppler effect for approach (or recession), $751 = 750\frac{340}{340-u}$ ***or*** $749 = 750\frac{340}{340+u}$;

to produce $u = 0.45\ \mathrm{m\,s^{-1}}$;

7. Police use radar to detect speeding cars. A police officer stands at the side of the road and points a radar device at an approaching car. The device emits microwaves which reflect off the car and return to the device. A change in frequency between the emitted and received microwaves is measured at the radar device. *[6 marks]*

The frequency change Δf is given by

$$\Delta f = \frac{2fv}{c}$$

where f is the transmitter frequency, v is the speed of the car and c is the wave speed.

The following data are available.

Transmitter frequency f = 40 GHz Δf = 9.5 kHz Maximum speed allowed = 28 m s^{-1}

(i) Explain the reason for the frequency change.

(ii) Suggest why there is a factor of 2 in the frequency-change equation.

(iii) Determine whether the speed of the car is below the maximum speed allowed.

Markscheme

i

mention of Doppler effect

OR

«relative» motion between source and observer produces frequency/wavelength change

Accept answers which refer to a double frequency shift.

*Award **[0]** if there is any suggestion that the wave speed is changed in the process.*

the reflected waves come from an approaching "source"

OR

the incident waves strike an approaching "observer"

increased frequency received «by the device ***or*** by the car»

ii

the car is a moving "observer" and then a moving "source", so the Doppler effect occurs twice

OR

the reflected radar appears to come from a "virtual image" of the device travelling at 2 v towards the device

iii

ALTERNATIVE 1

*For both alternatives, allow ecf to conclusion if v **OR** Δf are incorrectly calculated.*

v = «$\frac{(3\times10^8)\times(9.5\times10^3)}{(40\times10^9)\times2}=$» 36 «$ms^{-1}$»

«36> 28» so car exceeded limit

There must be a sense of a conclusion even if numbers are not quoted.

ALTERNATIVE 2

reverse argument using speed limit.

$\Delta f=$ «$\frac{2\times40\times10^9\times28}{3\times10^8}=$» 7500 «Hz»

« 9500> 7500» so car exceeded limit

There must be a sense of a conclusion even if numbers are not quoted.

This question is about sound.

A source emits sound of frequency f. The source is moving towards a stationary observer at constant speed. The observer measures the frequency of the sound to be f'.

8a. (i) Explain, using a diagram, why f' is greater than f. *[5 marks]*

(ii) The frequency f is 275 Hz. The source is moving at speed 20.0 ms^{-1}. The speed of sound in air is 330 ms^{-1}. Calculate the observed frequency f' of the sound.

Markscheme

(i) diagram showing (circular) wavefronts around source, so that wavefronts are closer together on side of observer;
speed of sound waves for observer is the same (as for stationary case) but observed wavelength is smaller;

since $f'=\frac{v}{\lambda'}$, (observed frequency is larger);

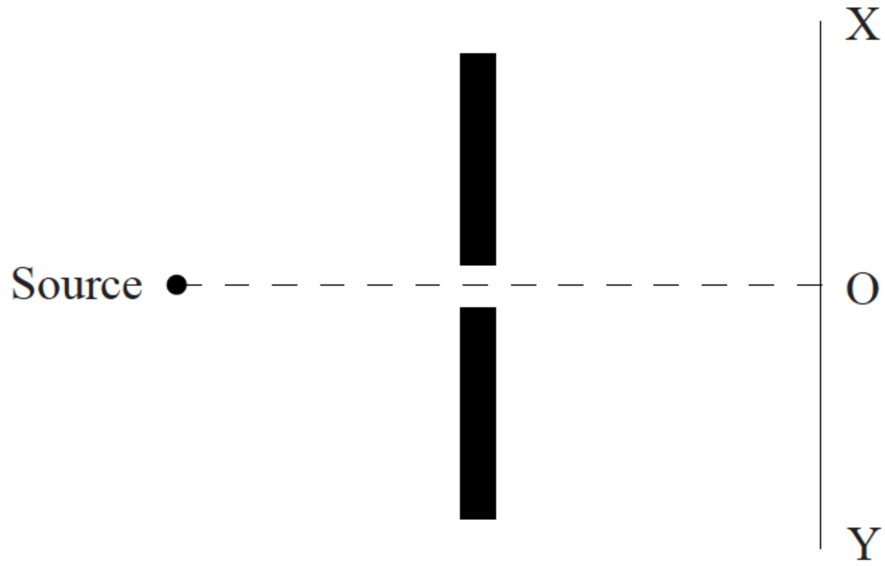
(ii) $f'\left(=f\left[\frac{v}{v-u_s}\right]\right)=275\left[\frac{330}{330-20}\right]$;
=293(Hz);

*Award **[0]** for use of moving observer formula.*

*Award **[1]** for use of $v+u_s$ to give 259 (Hz).*

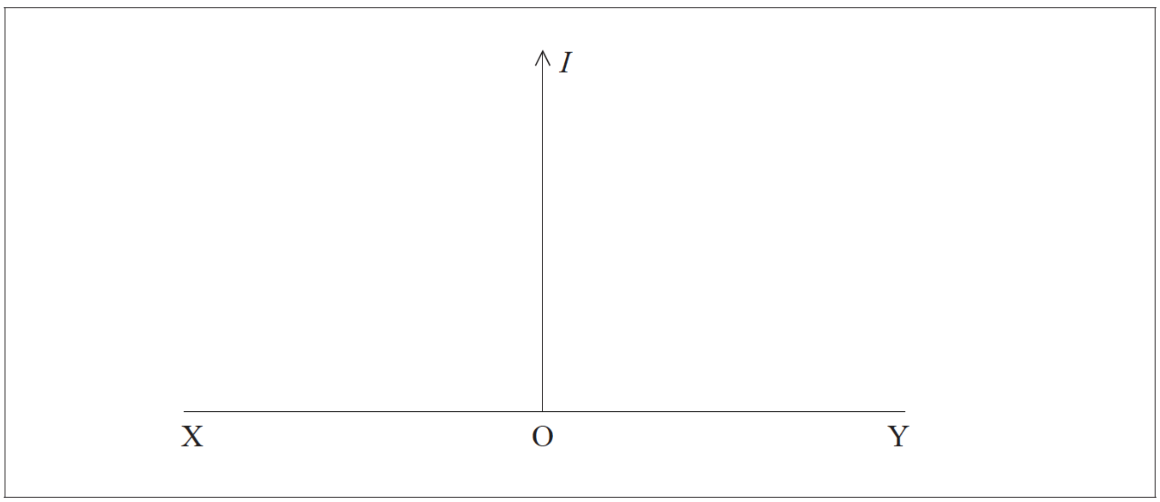
*Award **[2]** for a bald correct answer.*

8b. A source of sound is placed in front of a barrier that has an opening of width comparable to the wavelength of the sound. *[4 marks]*



A sound detector is moved along the line XY. The centre of XY is marked O.

(i) On the axes below, sketch a graph to show how the intensity *I* of the sound varies as the detector moves from X to Y.

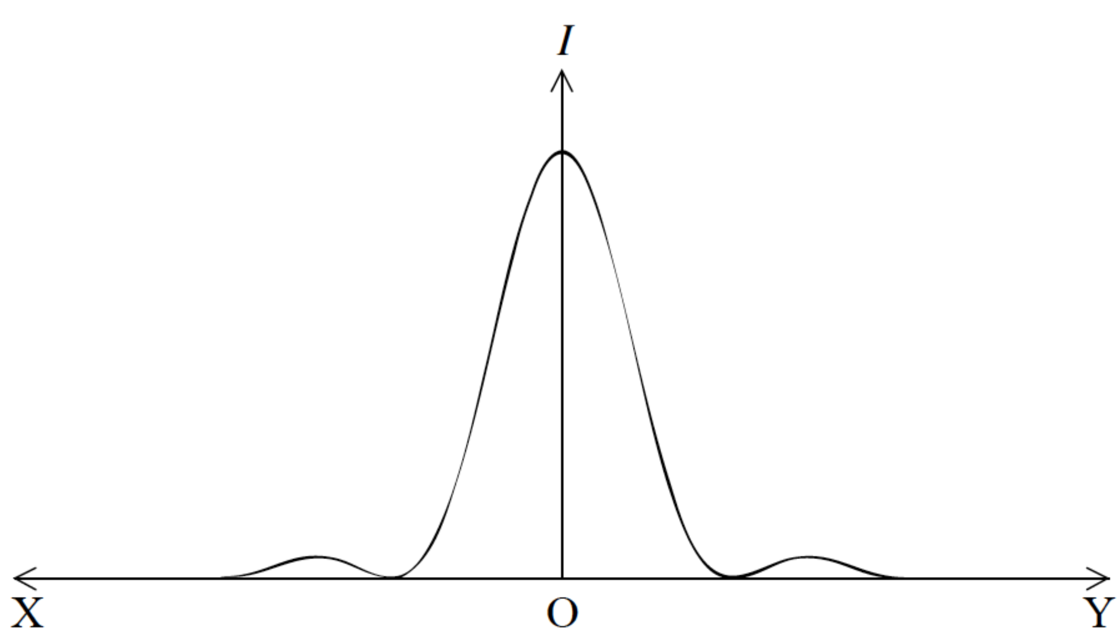


(ii) State the effect on the intensity pattern of increasing the wavelength of the sound.

Markscheme

(i) central symmetrical maximum;
at least one secondary maximum on each side, no more than one third the height of the central maximum; { *(judge by eye)*

minima drawn to zero, *ie* touching axis;
width of the secondary maximum half the width of the primary maximum; { *(judge by eye)*



(ii) greater distance between maxima/minima / pattern more spread out;

8c. (i) Outline the difference between a polarized wave and an unpolarized wave. *[3 marks]*

(ii) State why sound waves cannot be polarized.

Markscheme

(i) in a polarized wave, the oscillations/vibrations are in one direction/plane only;
in an unpolarized wave, the oscillations/vibrations are in all directions/ planes (perpendicular to the direction of energy transfer);
Must see mention of oscillations or vibrations in first or second marking point.

(ii) sound waves are longitudinal / the oscillations/vibrations are always parallel to direction of energy transfer;

Part 2 The Doppler effect and optical resolution

The Doppler effect can be used to deduce that a particular star X is moving towards Earth.

9a. Describe what is meant by the Doppler effect. *[2 marks]*

Markscheme

the observed change in frequency/wavelength of a wave;
emitted by a source moving away from or towards/relative to the observer;

9b. One of the lines in the spectrum of atomic hydrogen has a frequency of 4.6×10^{16}Hz as measured in the laboratory. The same line in the spectrum of star X is observed on Earth to be shifted by 1.3×10^{12}Hz. *[4 marks]*

(i) State the direction of the observed frequency shift.

(ii) Determine the speed at which X is moving towards Earth stating any assumption that you have made.

Markscheme

(i) a blue-shift / towards the blue end of the spectrum / to a higher frequency / *OWTTE*;

(ii) $v = \left(\frac{c\Delta f}{f} =\right) \frac{3\times10^8\times1.3\times10^{12}}{4.6\times10^{16}}$;
$8.5\times10^3 ms^{-1}$;
assume that the speed is very much less than speed of light;

This question is about the Doppler effect.

10. An ambulance is travelling at a speed of 28.0 ms^{-1} along a straight road. Its siren emits a continuous sound of frequency 520 Hz. The ambulance is approaching a stationary observer. The observer measures the frequency of the note to be 566 Hz. Determine the speed of sound. *[3 marks]*

Markscheme

recognize that $f' = \left[\frac{v}{v-u_s}\right] f$;

$566 = \left[\frac{v}{v-28}\right] 520$;

to give *v*=345(ms^{-1}) ;

*Award **[0]** for use of the moving observer Doppler equation.*
*Award **[2 max]** for the use of +28 to give -345(ms^{-1}).*
Otherwise award only the first marking point for substitution of the incorrect values in the correct equation.

This question is about the Doppler effect.

11. A spectral line from a source on Earth has a frequency of 4.672×10^{14} Hz. When this same line is observed from a distant galaxy it is found to have shifted to 4.669×10^{14} Hz. *[4 marks]*

(i) State the direction of the motion of the galaxy relative to Earth.

(ii) Deduce the speed of the galaxy relative to Earth.

Markscheme

(i) galaxy moving away from Earth;

(ii) rearranges data book equation thus $v \approx \frac{\Delta f}{f}c$;

$v = \frac{3.0\times10^{11}\times3\times10^8}{4.672\times10^{14}}$;
$v = 1.93\times10^5 ms^{-1}$;