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DOPPLER EFFECT**SECTION A: TYPICAL EXAM QUESTIONS****Question 1: 3 minutes**

A car is travelling towards you at $16 \text{ m}\cdot\text{s}^{-1}$ sounding its hooter with a frequency of 320 Hz . The velocity of sound is $330 \text{ m}\cdot\text{s}^{-1}$. What is the frequency of the sound that you will hear? [5]

(Remember to write down the formula with the $\pm$ before manipulating and changing it!)

Question 2: 8 minutes

Calculate the frequency heard by a stationary listener when an ambulance passes him at a speed of $25 \text{ m}\cdot\text{s}^{-1}$:

2.1. when the ambulance is moving towards him and [5]

2.2. when the ambulance is moving away from him. [5]

Take the speed of sound to be $340 \text{ m}\cdot\text{s}^{-1}$ and the frequency of the siren to be $1\,500 \text{ Hz}$.

(Remember to write down the formula with the $\pm$ before manipulating and changing it!)

Question 3: 3 minutes

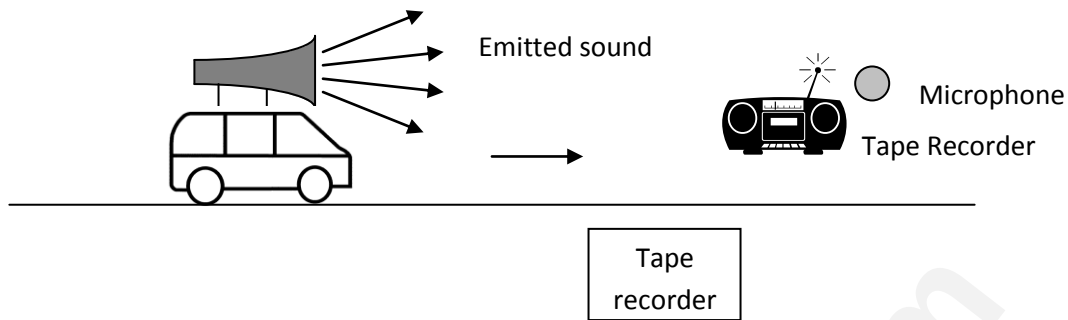
A flying bat emits squeaks at a frequency of 85 kHz . If a stationary observer picks up the frequency of the squeaks as 80 kHz , is the bat moving towards or away from the listener? Determine the speed at which the bat is flying. [5]

(Remember to write down the formula with the $\pm$ before manipulating and changing it!)

Question 4 : 11 minutes

(DoE Physics P1 Exemplar 2008)

During an experiment to determine the speed of sound, learners are given a siren that sounds a single note of frequency 426 Hz . They attach it to a remote controlled car and move it at constant speed past a stationary tape recorder which is mounted in the middle of a runway. Ignore the effects of friction. The tape recorder records the sound of the siren.



The learners make the following observation:

The pitch of the sound from the siren as it moved towards the tape recorder was higher than the pitch as the siren moved away from the recorder.

4.1 Name the effect which explains this observation. (2)

In one of the trials the speed of the remote controlled car was noted as $31 \text{ km} \cdot \text{h}^{-1}$. Two notes from the siren were recorded: one with a frequency of 437 Hz and the other note with a frequency lower than 426 Hz .

4.2 Convert $31 \text{ km} \cdot \text{h}^{-1}$ to $\text{m} \cdot \text{s}^{-1}$. (2)

4.3 Determine the speed of sound in air. (5)

4.4 Give a reason why the observed frequencies are respectively higher and lower than the frequency of the source (426 Hz). (2)
[11]

SECTION B: SOLUTIONS AND HINTS

Question 1:

$$f_L = \frac{v \pm v_L}{v \pm v_S} \cdot f_S \quad \checkmark$$

$$v \pm v_S$$

$$= \frac{330-0}{330-16} \times 320 \quad \checkmark$$

$$330-16 \quad \checkmark$$

$$= 336 \text{ Hz} \quad \checkmark$$

Learner Note: Note the frequency increases as the wave was compressed while the car travelled towards you.

Question 2:

2.1

$$f_L = \frac{v \pm v_L}{v \pm v_S} \cdot f_S \quad \checkmark$$

$$= \frac{340-0}{340-25} \times 1500 \quad \checkmark$$

$$= 1\,619 \text{ Hz} \quad \checkmark$$

2.2.

$$f_L = \frac{v \pm v_L}{v \pm v_S} \cdot f_S \quad \checkmark$$

$$= \frac{340-0}{340+25} \times 1500 \quad \checkmark$$

$$= 1\,397 \text{ Hz} \quad \checkmark$$

Question 3:

$$f_L = \frac{v \pm v_L}{v \pm v_S} \cdot f_S \quad \checkmark$$

$$80\,000 \checkmark = \frac{335}{335 \pm v_S} \times 85\,000 \quad \checkmark$$

$$= 20,93 \text{ m} \cdot \text{s}^{-1} \text{ away from the listener} \quad \checkmark$$

Question 4:

4.1 Doppler Effect ✓✓ (2)

4.2 $31 \text{ km} \cdot \text{h}^{-1} = \frac{31\,000}{3600} \checkmark = 8,61 \text{ m} \cdot \text{s}^{-1} \checkmark$ (2)

4.3 $f_L = \frac{v}{v - v_S} f_S \checkmark$

$$437 \checkmark = \frac{v}{v - 8,61} (426) \checkmark \checkmark$$

$$v = 342,05 \text{ m} \cdot \text{s}^{-1} \checkmark \quad (5)$$

4.4 Higher frequency: source is moving towards observer. ✓ (2)

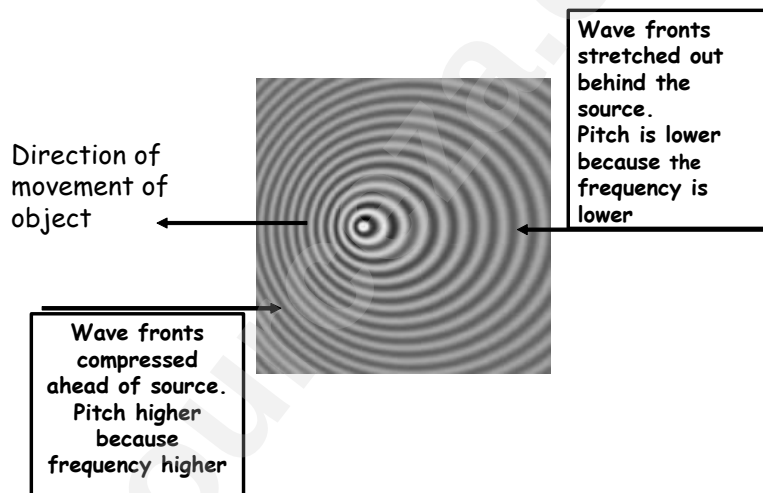
Lower frequency: source is moving away from observer. ✓ [11]

SECTION C: ADDITIONAL CONTENT NOTES

1.1 The Doppler Effect

When the source of a sound is moving towards you, the pitch sounds higher than that of the source.

When the source moves away from you, the pitch sounds lower.



Doppler Effect Equation

$$f_L = \frac{v \pm v_L}{v \pm v_S} \cdot f_S$$

f_L – frequency heard by listener

f_S – frequency of source

v_L – velocity of listener

v_S – velocity of source

v – speed of sound (this varies in different media and must be given. Air usually $330\text{m}\cdot\text{s}^{-1}$ – $340\text{m}\cdot\text{s}^{-1}$)

Generally, the direction from the listener (L) towards the source (s) is taken as positive (+).

If the source and the listener move towards each other	If the source and the listener move away from each other
The frequency that is being observed, f_L, will be higher than the emitted frequency, f_s. The equation then becomes $f_L = \frac{v + v_L}{v - v_s} \cdot f_s$ because $v \pm v_L$ must be greater than $v \pm v_s$ thus the + sign is used in the numerator and the – in the denominator.	The frequency that is being observed will be lower than the frequency being emitted. The equation then becomes $f_L = \frac{v - v_L}{v + v_s} \cdot f_s$ because $v \pm v_L$ must be smaller than $v \pm v_s$ thus the – sign is used in the numerator and the + sign is used in the denominator.

1.2 Uses

The blood flow in the heart and foetal heart beats can be detected using Doppler flow meters. This is not the same as ultra sound images.

Ultrasonic waves are emitted by a transmitter and then reflected by the object that is moving. The speed of the moving object i.e. the foetal heart beat etc, can be determined by the change in the frequency that is observed.

1.3 Red Shift

All stars emit white light. From earth when we look at stars moving away from the earth, they will display light with longer wavelengths – the red colours of the spectrum, due to the

Doppler Effect. As the stars move away, the wavelength elongates. This supports the Big Bang theory.

2. Speed of sound and Sonic boom

Certain objects can travel at the speed of sound (approximately $330 \text{ m}\cdot\text{s}^{-1}$). We talk about speeds similar to the speed of sound in terms of Mach number. This is just a ratio.

$$\text{Mach number} = \frac{\text{speed of object}}{\text{speed of sound}}$$



Approaching
speed of
sound.
Doppler
effect

Travelling at
speed of sound.
Mach 1. Massive
constructive
interference.
Huge pressure.
Associated
sound

Beyond
Mach 1.
Core shock
wave

Source: JM Lucas – The Science Tutor

As an object approaches the speed of sound the pitch perceived by an observer in front of the object will be higher since the waves compress.

At the speed of sound a loud sound (sonic boom) is heard as all the waves reinforce one another.

When an object travels faster than the speed of sound, an observer will hear nothing in front of the object but a shock wave (loud sound) will be heard in a conical area behind the object.

SECTION D: HOMEWORK

Question 1 – 15 minutes

An ambulance is dispatched to see to any injured passengers. The ambulance siren emits sound waves with a frequency of 500 Hz. The speed of sound in air at this location is $340 \text{ m} \cdot \text{s}^{-1}$.

- 1.1 Calculate the wavelength of the sound waves emitted by the ambulance siren. (2)
- 1.2 How would you know from the sound of the siren if it is moving towards you or away from you? (2)
- 1.3 Name the effect that changes the sound of the ambulance as it drives towards you. (1)
- 1.4 Calculate the speed of the ambulance relative to you (a stationary observer) when you hear the siren sound at 495 Hz. (5)

[10]

Question 2 – 10 minutes

A spectator at the Formula 1 Grand Prix notices that the sound of the car engines has a higher pitch when the cars are moving towards him and a lower pitch when they move away.



- 2.1 Explain with the aid of a diagram why this occurs. (2)
- 2.2 Why is this change in frequency more noticeable at the Formula 1 race than for a car passing a person standing on the pavement in a suburban area? (2)
- 2.3 If the sound produced by the engine of a formula 1 car is 250 Hz, calculate the frequency of the sound the spectator will hear if the car is approaching him at $200 \text{ km} \cdot \text{h}^{-1}$. (Take the speed of sound to be $340 \text{ m} \cdot \text{s}^{-1}$) (4)

[8]

SECTION E: SOLUTIONS TO SESSION 9 HOMEWORK

Question 1

$$E = hf$$

$$1,89 \times 10^{-24} = (6,6 \times 10^{-34})f$$

$$f = 2,9 \times 10^9 \text{ Hz} \checkmark$$

This frequency corresponds to the radio wave region of the electromagnetic spectrum. $\checkmark$

Question 2

$$2.1 \quad v = \lambda f \checkmark$$

$$3 \times 10^8 = \lambda (405 \times 10^6) \checkmark$$

$$\lambda = 0,74 \text{ m} \checkmark$$

$$2.2 \text{ radio} \checkmark \checkmark$$

$$2.3 \quad E = hf \checkmark = (6,6 \times 10^{-34}) \checkmark (405 \times 10^6) \checkmark \\ = 2,67 \times 10^{-25} \text{ J} \checkmark$$

Question 3

- 3.1 The yellow filter transmits red and green $\checkmark$ and absorbs blue light. $\checkmark$
The cyan filter transmits the green light $\checkmark$ and absorbs the red light. $\checkmark$

- 3.2 Red $\checkmark$