Higher Grade Physics

OUR DYNAMIC UNIVERSE

The Expanding Universe

The Doppler Effect

1. In the following sentences the words represented by the letters A, B, C and D are missing:
   Match each letter with the correct word from the list below:

   Doppler effect higher louder lower quieter softer

   A moving source emits a sound with frequency fs. When the source is moving towards a stationary observer, the observer hears a ____A_____ frequency f_o. When the source is moving away from a stationary observer, the observer hears a ____B_____ frequency f_o. This is known as the ___C___ ____D_____.

2. Write down the expression for the observed frequency fo, detected when a source of sound waves in air of frequency fs moves:
   (a) towards a stationary observer at a constant speed, v_s
   (b) away from a stationary observer at a constant speed, v_s.

3. In the table shown, calculate the value of each missing quantity (a) to (f), for a source of sound moving in air relative to a stationary observer.

Frequency heard by stationary observer / Hz	*Frequency of source /* Hz	*Speed of source moving towards observer /* m s^{-1}	*Speed of source moving away from observer /* m s^{-1}
(a)	400	10	–
(b)	400	–	10
850	(c)	20	–
1020	(d)	–	5
2125	2000	(e)	–
170	200	–	(f)

4. A girl tries out an experiment to illustrate the Doppler effect by spinning a battery-operated siren around her head. The siren emits sound waves with a frequency of 1200 Hz.

   Describe what would be heard by a stationary observer standing a few metres away.

5. A police car emits sound waves with a frequency of 1000 Hz from its siren. The car is travelling at 20 m s^{-1}.

   (a) Calculate the frequency heard by a stationary observer as the police car moves towards her.
   (b) Calculate the frequency heard by the same observer as the police car moves away from her.

6. A student is standing on a station platform. A train approaching the station sounds its horn as it passes through the station. The train is travelling at a speed of 25 m s−1. The horn has a frequency of 200 Hz.

   (a) Calculate the frequency heard as the train is approaching the student.
   (b) Calculate the frequency heard as the train is moving away from the student.

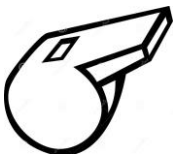
7. A man standing at the side of the road hears the horn of an approaching car. He hears a frequency of 470 Hz. The horn on the car has a frequency of 450 Hz.

   Calculate the speed of the car.

8. A source of sound emits waves of frequency 500 Hz. This is detected as 540 Hz by a stationary observer as the source of sound approaches.

   Calculate the frequency of the sound detected as the source moves away from the stationary observer.

9. A whistle of frequency 540 vibrations per second rotates in a circle of radius 0·75 m with a speed of 10 m s^{-1}. Calculate the lowest and highest frequency heard by a listener some distance away at rest with respect to the centre of the circle.



10. A woman is standing at the side of a road. A lorry, moving at 20 m s^{-1}, sounds its horn as it is passing her. The lorry is moving at 20 m s^{-1} and the horn has a frequency of 300 Hz.

    (a) Calculate the wavelength heard by the woman when the lorry is approaching her.
    (b) Calculate the wavelength heard by the woman when the lorry is moving away from her.

11. A siren emitting a sound of frequency 1000 vibrations per second moves away from you towards the base of a vertical cliff at a speed of 10 m s^{-1}.

    (a) Calculate the frequency of the sound you hear coming directly from the siren.

    (b) Calculate the frequency of the sound you hear reflected from the cliff.

12. A sound source moves away from a stationary listener. The listener hears a frequency that is 10% lower than the source frequency. Calculate the speed of the source.

13. A bat flies towards a tree at a speed of 3·60 m s^{-1} while emitting sound of frequency 350 kHz. A moth is resting on the tree directly in front of the bat.

    (a) Calculate the frequency of sound heard by the bat.

    (b) The bat decreases its speed towards the tree. Does the frequency of sound heard by the moth increase, decrease or stays the same? Justify your answer.

    (c) The bat now flies directly away from the tree with a speed of 4·50 m s^{-1} while emitting the same frequency of sound. Calculate the new frequency of sound heard by the moth.

14. The siren on a police car has a frequency of 1500 Hz. The police car is moving at a constant speed of 54 km h^{-1}.

    (a) Show that the police car is moving at 15 m s^{-1}.

    (b) Calculate the frequency heard when the car is moving towards a stationary observer.

    (c) Calculate the frequency heard when the car is moving away from a stationary observer.

15. A source of sound emits a signal at 600 Hz. This is observed as 640 Hz by a stationary observer as the source approaches.

    Calculate the speed of the moving source.

16. A battery-operated siren emits a constant note of 2200 Hz. It is rotated in a circle of radius 0·8 m at 3·0 revolutions per second. A stationary observer, standing some distance away, listens to the note made by the siren.

    (a) Show that the siren has a constant speed of 15·1 m s^{-1}.

    (b) Calculate the minimum frequency heard by the observer.

    (c) Calculate the maximum frequency heard by the observer.

17. You are standing at the side of the road. An ambulance approaches you with its siren on. As the ambulance approaches, you hear a frequency of 460 Hz and as the ambulance moves away from you, a frequency of 410 Hz. The nearest hospital is 3 km from where you are standing. Assuming that the ambulance maintains a constant speed during its journey to the hospital, estimate the time for the ambulance to reach the hospital.

18. On the planet Lats, a nattra moves towards a stationary ndo at 10 m s^{-1}. The nattra emits sound waves of frequency 1100 Hz. The stationary ndo hears a frequency of 1200 Hz.

    Calculate the speed of sound on the planet Lats.

19. In the following sentences the words represented by the letters A, B, C, D and E are missing: Match each letter with the correct word from the list below:

away blue longer red shorter towards

A hydrogen source of light gives out a number of emission lines. The wavelength of one of these lines is measured. When the light source is on the Earth, and at rest, the value of this wavelength is λ_{rest}. When the same hydrogen emission line is observed, on the Earth, in light coming from a distant star the value of the wavelength is $\lambda_{observed}$.

When a star is moving away from the Earth $\lambda_{observed}$ is ____A_____ than λ_{rest}. This is known as the ____B_____ shift.
When the distant star is moving towards the Earth $\lambda_{observed}$ is ____C_____ than λ_{rest}. This is known as the ____D_____ shift.
Measurements on many stars indicate that most stars are moving ____E_____ from the Earth.

20. In the table shown, calculate the value of each missing quantity.

Fractional change in wavelength, z	*Wavelength of light on Earth* λ_{rest} / nm	*Wavelength of light observed from star,* $\lambda_{observed}$ / nm
(a)	365	402
(b)	434	456
$8{\cdot}00 \times 10^{-2}$	486	(c)
$4{\cdot}00 \times 10^{-2}$	656	(d)
$5{\cdot}00 \times 10^{-2}$	(e)	456
$1{\cdot}00 \times 10^{-1}$	(f)	402

Hubble's Law

In the following questions, when required, use the approximation for Ho = $2{\cdot}4 \times 10^{-18}\ s^{-1}$

21. Convert the following distances in light years into distances in metres.

(a) 1 light year
(b) 50 light years
(c) 100, 000 light years
(d) 16, 000, 000, 000 light years

22. Convert the following distances in metres into distances in light years.

(a) Approximate distance from the Earth to our Sun = $1{\cdot}44 \times 10^{11}$ m.
(b) Approximate distance from the Earth to next nearest star Alpha Centauri = 3.97×10^{16} m.
(c) Approximate distance from the Earth to a galaxy in the constellation of Virgo = $4{\cdot}91 \times 10^{23}$ m.

23. In the table shown, calculate the value of each missing quantity.

Speed of galaxy relative to Earth / m s^{-1}	*Approximate distance from Earth to galaxy / m*	*Fractional change in wavelength, z*
(a)	7.10×10^{22}	(b)
(c)	1.89×10^{24}	(d)
$1{\cdot}70 \times 10^{6}$	(e)	(f)
$2{\cdot}21 \times 10^{6}$	(g)	(h)

24. Light from a distant galaxy is found to contain the spectral lines of hydrogen. The light causing one of these lines has a measured wavelength of 466 nm. When the same line is observed from a hydrogen source on Earth it has a wavelength of 434 nm.

    (a) Calculate the Doppler shift, z, for this galaxy.

    (b) Calculate the speed at which the galaxy is moving relative to the Earth.

    (c) In which direction, towards or away from the Earth, is the galaxy moving?

25. Light of wavelength 505 nm forms a line in the spectrum of an element on Earth. The same spectrum from light from a galaxy in Ursa Major shows this line shifted to correspond to light of wavelength 530 nm.

    (a) Calculate the speed that the galaxy is moving relative to the Earth.

    (b) Calculate the approximate distance, in metres, the galaxy is from the Earth.

26. A galaxy is moving away from the Earth at a speed of 0·074 c.

    (a) Convert 0·074 c into a speed in m s^{-1}.

    (b) Calculate the approximate distance, in metres, of the galaxy from the Earth.

27. A distant star is travelling directly away from the Earth at a speed of $2{\cdot}4 \times 10^{7}$ m s^{-1}.

    (a) Calculate the value of z for this star.

    (b) A hydrogen line in the spectrum of light from this star is measured to be 443 nm. Calculate the wavelength of this line when it observed from a hydrogen source on the Earth.

28. A line in the spectrum from a hydrogen atom has a wavelength of 489 nm on the Earth. The same line is observed in the spectrum of a distant star but with a longer wavelength of 538 nm.

    (a) Calculate the speed, in m s^{-1}, at which the star is moving away from the Earth.

    (b) Calculate the approximate distance, in metres and in light years, of the star from the Earth.

29. The galaxy Corona Borealis is approximately 1 000 million light years away from the Earth. Calculate the speed at which Corona Borealis is moving away from the Earth.

30. A galaxy is moving away from the Earth at a speed of $3{\cdot}0 \times 10^{7}$ m s^{-1}. The frequency of an emission line coming from the galaxy is measured. The light forming the same emission line, from a source on Earth, is observed to have a frequency of $5{\cdot}00 \times 10^{14}$ Hz.

    (a) Show that the wavelength of the light corresponding to the emission line from the source on the Earth is $6{\cdot}00 \times 10^{-7}$ m.

    (b) Calculate the frequency of the light forming the emission line coming from the galaxy.

31. A distant quasar is moving away from the Earth. Hydrogen lines are observed coming from this quasar. One of these lines is measured to be 20 nm longer than the same line, of wavelength 486 nm from a source on Earth.

    (a) Calculate the speed at which the quasar is moving away from the Earth.

    (b) Calculate the approximate distance, in millions of light years, that the quasar is from the Earth.

32. A hydrogen source, when viewed on the Earth, emits a red emission line of wavelength 656 nm. Observations, for the same line in the spectrum of light from a distant star, give a wavelength of 660 nm. Calculate the speed of the star relative to the Earth.

33. Due to the rotation of the Sun, light waves received from opposite ends of a diameter on the Sun show equal but opposite Doppler shifts. The relative speed of rotation of a point on the end of a diameter of the Sun relative to the Earth is 2 km s^{-1}. Calculate the wavelength shift for a hydrogen line of wavelength 486·1 nm on the Earth.

Big Bang Theory

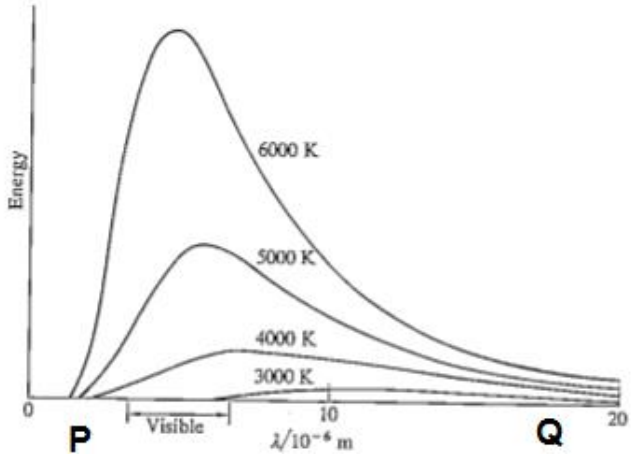
34. Experimental work at CERN has been described as "*recreating the conditions that occurred just after the Big Bang*".

    Describe what scientists mean by the *Big Bang theory* and give three pieces of evidence which support this theory.

35. Radiation of peak wavelength 1.06 mm can be detected on Earth coming from all directions in space.

    What name is given to this radiation?

36. The graphs below are obtained by measuring the energy emitted at different wavelengths from an object at different temperatures.



(a) Which part of the x-axis, P or Q, corresponds to ultraviolet radiation?

(b) What do the graphs show happens to the amount of energy emitted at a certain wavelength as the temperature of the object increases?

(c) What do the graphs show happens to the total energy radiated by the object as its temperature increases?

(d) Each graph shows that there is a wavelength λ_{max} at which the maximum amount of energy is emitted.

(i) Explain why the value of λ_{max} decreases as the temperature of the object increases.
The table shows the values of λ_{max} at different temperatures of the object.

Temperature /K	λ_{max} / m
6000	$4{\cdot}8 \times 10^{-7}$
5000	$5{\cdot}8 \times 10^{-7}$
4000	$7\,3 \times 10^{-7}$
3000	$9{\cdot}7 \times 10^{-7}$

(ii) Use this data to determine the relationship between temperature T and λ_{max}.

(e) Use your answer to (d) (ii) to calculate:

(i) the temperature of the star Sirius where λ_{max} is $2{\cdot}7 \times 10^{-7}$ m

(ii) the value of λ_{max} for the star Alpha Crucis which has a temperature of 23,000 K

(iii) the temperature of the present universe when λ_{max} for the cosmic microwave radiation is measured as $1{\cdot}1 \times 10^{-3}$ m.

(iv) the approximate wavelength and type of the radiation emitted by your skin,