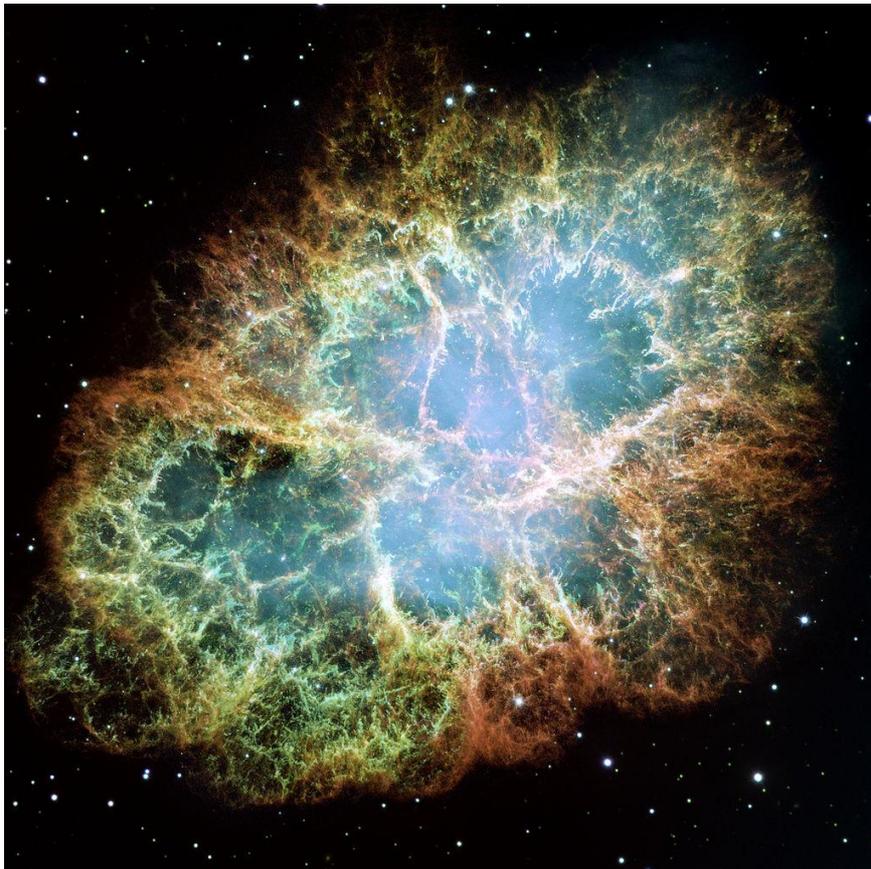




Higher Physics

Our Dynamic Universe



Problems Part 2

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Section 5: Gravitation

Gravity and mass

In the following questions, when required, use the following data:

Gravitational constant = $6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

1. State the inverse square law of gravitation.
2. Show that the force of attraction between two large ships, each of mass $5.00 \times 10^7 \text{ kg}$ and separated by a distance of 20 m, is 417 N.
3. Calculate the gravitational force between two cars parked 0.50 m apart. The mass of each car is 1000 kg.
4. In a hydrogen atom an electron orbits a proton in a circle with a radius of $5.30 \times 10^{-11} \text{ m}$. The mass of an electron is $9.11 \times 10^{-31} \text{ kg}$ and the mass of a proton is $1.67 \times 10^{-27} \text{ kg}$. Calculate the gravitational force of attraction between the proton and the electron in a hydrogen atom.
5. The distance between the Earth and the Sun is $1.50 \times 10^{11} \text{ m}$. The mass of the Earth is $5.98 \times 10^{24} \text{ kg}$ and the mass of the Sun is $1.99 \times 10^{30} \text{ kg}$. Calculate the gravitational force between the Earth and the Sun.
6. Two protons exert a gravitational force of $1.16 \times 10^{-35} \text{ N}$ on each other. The mass of a proton is $1.67 \times 10^{-27} \text{ kg}$. Calculate the distance separating the protons.

Section 6: Special relativity

Relativity – Fundamental principles

1. A river flows at a constant speed of 0.5 m s^{-1} south. A canoeist is able to row at a constant speed of 1.5 m s^{-1} .
 - (a) Determine the velocity of the canoeist relative to the river bank when the canoeist is moving upstream.
 - (b) Determine the velocity of the canoeist relative to the river bank when the canoeist is moving downstream.
2. In an airport, passengers use a moving walkway. The moving walkway is travelling at a constant speed of 0.8 m s^{-1} and is travelling east. For the following people, determine the velocity of the person relative to the ground:
 - (a) a woman standing at rest on the walkway;
 - (b) a man walking at 2.0 m s^{-1} in the same direction as the walkway is moving;
 - (c) a boy running west at 3.0 m s^{-1} .
3. The steps of an escalator move at a steady speed of 1.0 m s^{-1} relative to the stationary side of the escalator.
 - (a) A man walks up the steps of the escalator at 2.0 m s^{-1} . Determine the speed of the man relative to the side of the escalator.
 - (b) A boy runs down the steps of the escalator at 3.0 m s^{-1} . Determine the speed of the boy relative to the side of the escalator.
4. In the following sentences the words represented by the letters A, B, C, D, E, F and G are missing:

Match each letter with the correct word from the list below:

| | | | |
|--------------|----------------|------------|-----------|
| acceleration | different | Einstein's | fast |
| lengthened | Newton's | same | shortened |
| slow | speed of light | velocity | zero |

In _____ **A** _____ Theory of Special Relativity the laws of physics are the _____ **B** _____ for all observers, at rest or moving at constant velocity with respect to each other ie _____ **C** _____ acceleration.

An observer, at rest or moving at constant _____ **D** _____ has their own frame of reference.

In all frames of reference the _____ **E** _____, c , remains the same regardless of whether the source or observer is in motion.

Einstein's principles that the laws of physics and the speed of light are the same for all observers leads to the conclusion that moving clocks run _____ **F** _____ (time dilation) and moving objects are _____ **G** _____ (length contraction).

5. An observer at rest on the Earth sees an aeroplane fly overhead at a constant speed of 2000 km h^{-1} . At what speed, in km h^{-1} , does the pilot of the aeroplane see the Earth moving?
6. A scientist is in a windowless lift. Can the scientist determine whether the lift is moving with a:
 - (a) uniform velocity
 - (b) uniform acceleration?
7. Spaceship A is moving at a speed of $2.4 \times 10^8 \text{ m s}^{-1}$. It sends out a light beam in the forwards direction. Meanwhile another spaceship B is moving towards spaceship A at a speed of $2.4 \times 10^8 \text{ m s}^{-1}$. At what speed does spaceship B see the light beam from spaceship A pass?
8. A spacecraft is travelling at a constant speed of $7.5 \times 10^7 \text{ m s}^{-1}$. It emits a pulse of light when it is $3.0 \times 10^{10} \text{ m}$ from the Earth as measured by an observer on the Earth.
Calculate the time taken for the pulse of light to reach the Earth according to a clock on the Earth when the spacecraft is moving:
 - (a) away from the Earth;
 - (b) towards the Earth.
9. A spaceship is travelling away from the Earth at a constant speed of $1.5 \times 10^8 \text{ m s}^{-1}$. A light pulse is emitted by a lamp on the Earth and travels towards the spaceship. Find the speed of the light pulse according to an observer on:
 - (a) the Earth;
 - (b) the spaceship.
10. Convert the following fraction of the speed of light into a value in m s^{-1} :
 - (a) $0.1 c$
 - (b) $0.5 c$
 - (c) $0.6 c$
 - (d) $0.8 c$
11. Convert the following speeds into a fraction of the speed of light:
 - (a) $3.0 \times 10^8 \text{ m s}^{-1}$
 - (b) $2.0 \times 10^8 \text{ m s}^{-1}$
 - (c) $1.5 \times 10^8 \text{ m s}^{-1}$
 - (d) $1.0 \times 10^8 \text{ m s}^{-1}$

Relativity – Time dilation

- Write down the relationship involving the proper time t and dilated time t' between two events which are observed in two different frames of reference moving at a speed, v , relative to one another (where the proper time is the time measured by an observer at rest with respect to the two events and the dilated time is the time measured by another observer moving at a speed, v , relative to the two events).
- In the table shown, use the relativity equation for time dilation to calculate the value of each missing quantity (a) to (f) for an object moving at a constant speed relative to the Earth.

| <i>Dilated time</i> | <i>Proper time</i> | <i>Speed of object / m s⁻¹</i> |
|-------------------------|--------------------|---|
| (a) | 20 h | 1.00×10^8 |
| (b) | 10 year | 2.25×10^8 |
| 1400 s | (c) | 2.00×10^8 |
| 1.40×10^{-4} s | (d) | 1.00×10^8 |
| 84 s | 60 s | (e) |
| 21 minutes | 20 minutes | (f) |

- Two observers P and Q synchronise their watches at 11.00 am just as observer Q passes the Earth at a speed of 2×10^8 m s⁻¹.
 - At 11:15 am according to observer P's watch, observer P looks at Q's watch through a telescope. Calculate the time, to the nearest minute, that observer P sees on Q's watch.
 - At 11:15 am according to observer Q's watch, observer Q looks at P's watch through a telescope. Calculate the time, to the nearest minute, that observer Q sees on P's watch.
- The lifetime of a star is 10 billion years as measured by an observer at rest with respect to the star. The star is moving away from the Earth at a speed of 0.81 c.
Calculate the lifetime of the star according to an observer on the Earth.
- A spacecraft moving with a constant speed of 0.75 c passes the Earth. An astronaut on the spacecraft measures the time taken for Usain Bolt to run 100 m in the sprint final at the 2008 Olympic Games. The astronaut measures this time to be 14.65 s.
Calculate Usain Bolt's winning time as measured on the Earth.
- A scientist in the laboratory measures the time taken for a nuclear reaction to occur in an atom. When the atom is travelling at 8.0×10^7 m s⁻¹ the reaction takes 4.0×10^{-4} s.
Calculate the time for the reaction to occur when the atom is at rest.

7. The light beam from a lighthouse sweeps its beam of light around in a circle once every 10 s. To an astronaut on a spacecraft moving towards the Earth, the beam of light completes one complete circle every 14 s.
Calculate the speed of the spacecraft relative to the Earth.
8. A rocket passes two beacons that are at rest relative to the Earth. An astronaut in the rocket measures the time taken for the rocket to travel from the first beacon to the second beacon to be 10.0 s. An observer on Earth measures the time taken for the rocket to travel from the first beacon to the second beacon to be 40.0 s.
Calculate the speed of the rocket relative to the Earth.
9. A spacecraft travels to a distant planet at a constant speed relative to the Earth. A clock on the spacecraft records a time of 1 year for the journey while an observer on Earth measures a time of 2 years for the journey.
Calculate the speed, in m s^{-1} , of the spacecraft relative to the Earth.

Relativity – Length contraction

1. Write down the relationship involving the proper length l and contracted length l' of a moving object observed in two different frames of reference moving at a speed, v , relative to one another (where the proper length is the length measured by an observer at rest with respect to the object and the contracted length is the length measured by another observer moving at a speed, v , relative to the object).
2. In the table shown, use the relativity equation for length contraction to calculate the value of each missing quantity (a) to (f) for an object moving at a constant speed relative to the Earth.

| <i>Contracted length</i> | <i>Proper length</i> | <i>Speed of object / m s⁻¹</i> |
|--------------------------|----------------------|---|
| (a) | 5.00 m | 1.00×10^8 |
| (b) | 15.0 m | 2.00×10^8 |
| 0.15 km | (c) | 2.25×10^8 |
| 150 mm | (d) | 1.04×10^8 |
| 30 m | 35 m | (e) |
| 10 m | 11 m | (f) |

3. A rocket has a length of 20 m when at rest on the Earth. An observer, at rest on the Earth, watches the rocket as it passes at a constant speed of $1.8 \times 10^8 \text{ m s}^{-1}$. Calculate the length of the rocket as measured by the observer.
4. A pi meson is moving at 0.90 c relative to a magnet. The magnet has a length of 2.00 m when at rest to the Earth. Calculate the length of the magnet in the reference frame of the pi meson.
5. In the year 2050 a spacecraft flies over a base station on the Earth. The spacecraft has a speed of 0.8 c. The length of the moving spacecraft is measured as 160 m by a person on the Earth. The spacecraft later lands and the same person measures the length of the now stationary spacecraft. Calculate the length of the stationary spacecraft.
6. A rocket is travelling at 0.50 c relative to a space station. Astronauts on the rocket measure the length of the space station to be 0.80 km. Calculate the length of the space station according to a technician on the space station.
7. A metre stick has a length of 1.00 m when at rest on the Earth. When in motion relative to an observer on the Earth the same metre stick has a length of 0.50 m. Calculate the speed, in m s^{-1} , of the metre stick.

8. A spaceship has a length of 220 m when measured at rest on the Earth. The spaceship moves away from the Earth at a constant speed and an observer, on the Earth, now measures its length to be 150 m. Calculate the speed of the spaceship in m s^{-1} .

9. The length of a rocket is measured when at rest and also when moving at a constant speed by an observer at rest relative to the rocket. The observed length is 99.0 % of its length when at rest. Calculate the speed of the rocket.

Relativity questions

- Two points A and B are separated by 240 m as measured by metre sticks at rest on the Earth. A rocket passes along the line connecting A and B at a constant speed. The time taken for the rocket to travel from A to B, as measured by an observer on the Earth, is 1.00×10^{-6} s.
 - Show that the speed of the rocket relative to the Earth is $2.40 \times 10^8 \text{ m s}^{-1}$.
 - Calculate the time taken, as measured by a clock in the rocket, for the rocket to travel from A to B.
 - What is the distance between points A and B as measured by metre sticks carried by an observer travelling in the rocket?
- A spacecraft is travelling at a constant speed of 0.95 c. The spacecraft travels at this speed for 1 year, as measured by a clock on the Earth.
 - Calculate the time elapsed, in years, as measured by a clock in the spacecraft.
 - Show that the distance travelled by the spacecraft as measured by an observer on the spacecraft is 2.8×10^{15} m.
 - Calculate the distance, in m, the spacecraft will have travelled as measured by an observer on the Earth.
- A pi meson has a mean lifetime of 2.6×10^{-8} s when at rest. A pi meson moves with a speed of 0.99 c towards the surface of the Earth.
 - Calculate the mean lifetime of this pi meson as measured by an observer on the Earth.
 - Calculate the mean distance travelled by the pi meson as measured by the observer on the Earth.
- A spacecraft moving at $2.4 \times 10^8 \text{ m s}^{-1}$ passes the Earth. An astronaut on the spacecraft finds that it takes 5.0×10^{-7} s for the spacecraft to pass a small marker which is at rest on the Earth.
 - Calculate the length, in m, of the spacecraft as measured by the astronaut.
 - Calculate the length of the spacecraft as measured by an observer at rest on the Earth.
- A neon sign flashes with a frequency of 0.2 Hz.
 - Calculate the time between flashes.
 - An astronaut on a spacecraft passes the Earth at a speed of 0.84 c and sees the neon light flashing. Calculate the time between flashes as observed by the astronaut on the spacecraft.
- When at rest, a subatomic particle has a lifetime of 0.15 ns. When in motion relative to the Earth the particle's lifetime is measured by an observer on the Earth as 0.25 ns. Calculate the speed of the particle.

7. A meson is 10.0 km above the Earth's surface and is moving towards the Earth at a speed of 0.999 c.
- (a) Calculate the distance, according to the meson, travelled before it strikes the Earth.
 - (b) Calculate the time taken, according to the meson, for it to travel to the surface of the Earth.
8. The star Alpha Centauri is 4.2 light years away from the Earth. A spacecraft is sent from the Earth to Alpha Centauri. The distance travelled, as measured by the spacecraft, is 3.6 light years.
- (a) Calculate the speed of the spacecraft relative to the Earth.
 - (b) Calculate the time taken, in seconds, for the spacecraft to reach Alpha Centauri as measured by an observer on the Earth.
 - (c) Calculate the time taken, in seconds, for the spacecraft to reach Alpha Centauri as measured by a clock on the spacecraft.
9. Muons, when at rest, have a mean lifetime of 2.60×10^{-8} s. Muons are produced 10 km above the Earth. They move with a speed of 0.995 c towards the surface of the Earth.
- (a) Calculate the mean lifetime of the moving muons as measured by an observer on the Earth.
 - (b) Calculate the mean distance travelled by the muons as measured by an observer on the Earth.
 - (c) Calculate the mean distance travelled by the muons as measured by the muons.

Section 7: The expanding universe

The Doppler effect and redshift of galaxies

In the following questions, when required, use the approximation for speed of sound in air = 340 m s^{-1} .

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 f_s . 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 f_o , detected when a source of sound waves in air of frequency f_s 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.

| <i>Frequency heard by stationary observer / Hz</i> | <i>Frequency of source / Hz</i> | <i>Speed of source moving towards observer / m s^{-1}</i> | <i>Speed of source moving away from observer / m s^{-1}</i> |
|--|---------------------------------|---|---|
| (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} .
- Calculate the frequency heard by a stationary observer as the police car moves towards her.
 - 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.
- Calculate the frequency heard as the train is approaching the student.
 - 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 0.75m 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.
- Calculate the wavelength heard by the woman when the lorry is approaching her.
 - 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} .
- Calculate the frequency of the sound you hear coming directly from the siren.
 - 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.
- Calculate the frequency of sound heard by the bat.
 - 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.
 - 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} .
- Show that the police car is moving at 15 m s^{-1} .
 - Calculate the frequency heard when the car is moving towards a stationary observer.
 - 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.
- Show that the siren has a constant speed of 15.1 m s^{-1} .
 - Calculate the minimum frequency heard by the observer.
 - 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 nattrra moves towards a stationary ndo at 10 m s^{-1} . The nattrra 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 $\lambda_{\text{observed}}$.

When a star is moving away from the Earth $\lambda_{\text{observed}}$ is **A** than λ_{rest} .

This is known as the **B** shift.

When the distant star is moving towards the Earth $\lambda_{\text{observed}}$ 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.

| <i>Fractional change in wavelength, z</i> | <i>Wavelength of light on Earth λ_{rest} / nm</i> | <i>Wavelength of light observed from star, $\lambda_{\text{observed}}$ / nm</i> |
|---|---|--|
| (a) | 365 | 402 |
| (b) | 434 | 456 |
| 8.00×10^{-2} | 486 | (c) |
| 4.00×10^{-2} | 656 | (d) |
| 5.00×10^{-2} | (e) | 456 |
| 1.00×10^{-1} | (f) | 402 |

Hubble's law

In the following questions, when required, use the approximation for $H_0 = 2.4 \times 10^{-18} \text{ s}^{-1}$

- Convert the following distances in light years into distances in metres.
 - 1 light year
 - 50 light years
 - 100, 000 light years
 - 16, 000, 000, 000 light years
- Convert the following distances in metres into distances in light years.
 - Approximate distance from the Earth to our Sun = $1.44 \times 10^{11} \text{ m}$.
 - Approximate distance from the Earth to next nearest star Alpha Centauri = $3.97 \times 10^{16} \text{ m}$.
 - Approximate distance from the Earth to a galaxy in the constellation of Virgo = $4.91 \times 10^{23} \text{ m}$.

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

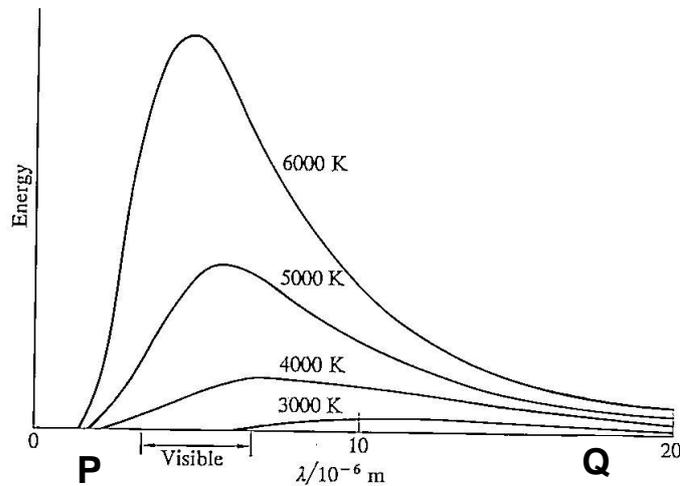
| <i>Speed of galaxy relative to Earth / m s^{-1}</i> | <i>Approximate distance from Earth to galaxy / m</i> | <i>Fractional change in wavelength, z</i> |
|---|--|---|
| (a) | 7.10×10^{22} | (b) |
| (c) | 1.89×10^{24} | (d) |
| 1.70×10^6 | (e) | (f) |
| 2.21×10^6 | (g) | (h) |

- 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.
 - Calculate the Doppler shift, z, for this galaxy.
 - Calculate the speed at which the galaxy is moving relative to the Earth.
 - In which direction, towards or away from the Earth, is the galaxy moving?
- 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.
 - Calculate the speed that the galaxy is moving relative to the Earth.
 - Calculate the approximate distance, in metres, the galaxy is from the Earth.
- A galaxy is moving away from the Earth at a speed of 0.074 c.
 - Convert 0.074 c into a speed in m s^{-1} .
 - Calculate the approximate distance, in metres, of the galaxy from the Earth.

7. A distant star is travelling directly away from the Earth at a speed of $2.4 \times 10^7 \text{ m s}^{-1}$.
- Calculate the value of z for this star.
 - 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.
8. 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.
- Calculate the speed, in m s^{-1} , at which the star is moving away from the Earth.
 - Calculate the approximate distance, in metres and in light years, of the star from the Earth.
9. 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.
10. A galaxy is moving away from the Earth at a speed of $3.0 \times 10^7 \text{ m s}^{-1}$. 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 $5.00 \times 10^{14} \text{ Hz}$.
- Show that the wavelength of the light corresponding to the emission line from the source on the Earth is $6.00 \times 10^{-7} \text{ m}$.
 - Calculate the frequency of the light forming the emission line coming from the galaxy.
11. 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.
- Calculate the speed at which the quasar is moving away from the Earth.
 - Calculate the approximate distance, in millions of light years, that the quasar is from the Earth.
12. 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.
13. 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.

Section 8: Big Bang theory

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



- Which part of the x-axis, P or Q, corresponds to ultraviolet radiation?
- What do the graphs show happens to the amount of energy emitted at a *certain* wavelength as the temperature of the object increases?
- What do the graphs show happens to the *total* energy radiated by the object as its temperature increases?
- Each graph shows that there is a wavelength λ_{max} at which the maximum amount of energy is emitted.
 - 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 | $\lambda_{\text{max}} / \text{m}$ |
|----------------|-----------------------------------|
| 6000 | 4.8×10^{-7} |
| 5000 | 5.8×10^{-7} |
| 4000 | 7.3×10^{-7} |
| 3000 | 9.7×10^{-7} |

- 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 2.7×10^{-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 1.1×10^{-3} m.
 - (iv) the approximate wavelength and type of the radiation emitted by your skin, assumed to be at a temperature of 33° C.

Numerical Solutions

Section 5: Gravitation

Gravity and mass

1. $F = \frac{Gm_1m_2}{r^2}$
3. $2.67 \times 10^{-4} \text{ N}$
4. $3.61 \times 10^{-47} \text{ N}$
5. $3.53 \times 10^{22} \text{ N}$
6. $4.00 \times 10^{-15} \text{ m}$

Section 5: Special relativity

Relativity – Fundamental principles

1. (a) 1.0 m s^{-1} north
(b) 2.0 m s^{-1} south
2. (a) 0.8 m s^{-1} east
(b) 2.8 m s^{-1} east
(c) 2.2 m s^{-1} west
3. (a) 3.0 m s^{-1}
(b) 2.0 m s^{-1}
4. A = Einstein's; B = same; C = zero; D = velocity; E = speed of light; F = slow; G = shortened
5. 2000 km h^{-1}
6. (a) No
(b) Yes
7. $3 \times 10^8 \text{ m s}^{-1}$
8. (a) 100 s
(b) 100 s
9. (a) $3 \times 10^8 \text{ m s}^{-1}$
(b) $3 \times 10^8 \text{ m s}^{-1}$

10. (a) $0.3 \times 10^8 \text{ m s}^{-1}$
 (b) $1.5 \times 10^8 \text{ m s}^{-1}$
 (c) $1.8 \times 10^8 \text{ m s}^{-1}$
 (d) $2.4 \times 10^8 \text{ m s}^{-1}$
11. (a) c
 (b) 0.67 c
 (c) 0.5 c
 (d) 0.33 c

Relativity – Time dilation

1. $t' = \frac{t}{\sqrt{1 - \left(\frac{v^2}{c^2}\right)}}$
2. (a) 21.2 h
 (b) 15.1 year
 (c) 1043 s
 (d) $1.32 \times 10^{-4} \text{ s}$
 (e) $2.10 \times 10^8 \text{ m s}^{-1}$
 (f) $9.15 \times 10^7 \text{ m s}^{-1}$
3. (a) 11.20 am
 (b) 11.20 am
4. 17.1 billion years
5. 9.69 s
6. $3.9 \times 10^{-4} \text{ s}$
7. $2.1 \times 10^8 \text{ m s}^{-1}$ or 0.70 c
8. $2.90 \times 10^8 \text{ m s}^{-1}$ or 0.97 c
9. $2.60 \times 10^8 \text{ m s}^{-1}$

Relativity – Length contraction

1. $l' = l \sqrt{1 - v^2/c^2}$
2. (a) 4.71 m
 (b) 11.2 m
 (c) 0.227 km
 (d) 160 mm
 (e) $1.55 \times 10^8 \text{ m s}^{-1}$
 (f) $1.25 \times 10^8 \text{ m s}^{-1}$

3. 16 m
4. 0.872 m
5. 267 m
6. 0.92 km
7. $2.60 \times 10^8 \text{ m s}^{-1}$
8. $2.19 \times 10^8 \text{ m s}^{-1}$
9. $4.23 \times 10^7 \text{ m s}^{-1}$ or 0.14 c

Relativity questions

1. (b) $1.67 \times 10^{-6} \text{ s}$
(c) 144 m
2. (a) 0.31 of a year
(c) $8.97 \times 10^{15} \text{ m}$
3. (a) $1.84 \times 10^{-7} \text{ s}$
(b) 54.6 m or 54.7 m
4. (a) 120 m
(b) 72 m
5. (a) 5 s
(b) 9.22 s
6. 0.8 c
7. (a) 447 m
(b) $1.49 \times 10^{-6} \text{ s}$
8. (a) 0.52 c
(b) $2.55 \times 10^8 \text{ s}$
(c) $2.18 \times 10^8 \text{ s}$
9. (a) $2.60 \times 10^{-7} \text{ s}$
(b) 77.6 m
(c) 7.75 m or 7.76 m

Section 6: The expanding universe

The Doppler effect and redshift of galaxies

1. A = higher; B = lower; C = Doppler; D = effect
2. (a) $f_0 = f_s \frac{v}{(v - v_s)}$
(b) $f_0 = f_s \frac{v}{(v + v_s)}$
3. (a) 412 Hz
(b) 389 Hz
(c) 800 Hz
(d) 1035 Hz
(e) 20 m s^{-1}
(f) 60 m s^{-1}
5. (a) 1063 Hz
(b) 944 Hz
6. (a) 216 Hz
(b) 186 Hz
7. 14.5 m s^{-1}
8. 466 Hz
9. 556 Hz, 525 Hz
10. (a) 1.07 m
(b) 1.2 m
11. (a) 971 Hz
(b) 1030 Hz
12. 37.8 m s^{-1}
13. (a) 354 kHz
(b) Decrease – denominator is larger
(c) 345 kHz
14. (b) 1569 Hz
(c) 1437 Hz
15. 21.3 m s^{-1}

16. (b) 2106 Hz
(c) 2302 Hz
17. 154 s
18. 120 m s^{-1}
19. A = longer; B = red; C = shorter; D = blue; E = away
20. (a) 1.01×10^{-1}
(b) 5.07×10^{-2}
(c) 525 nm
(d) 682 nm
(e) 434 nm
(f) 365 nm

Hubble's law

1. (a) $9.46 \times 10^{15} \text{ m}$
(b) $4.73 \times 10^{17} \text{ m}$
(c) $9.46 \times 10^{20} \text{ m}$
(d) $1.51 \times 10^{26} \text{ m}$
2. (a) 1.52×10^{-5} light years
(b) 4.2 light years
(c) 5.19×10^7 light years

3.

| $v / \text{m s}^{-1}$ | d / m | z |
|-----------------------|-----------------------|------------------------|
| 1.70×10^5 | 7.10×10^{22} | 5.67×10^{-4} |
| 4.54×10^6 | 1.89×10^{24} | 1.51×10^{-2} |
| 1.70×10^6 | 7.08×10^{23} | 5.667×10^{-2} |
| 2.21×10^6 | 9.21×10^{23} | 7.37×10^{-3} |

4. (a) 7.37×10^{-2}
(b) $2.21 \times 10^7 \text{ m s}^{-1}$
(c) Away
5. (a) $1.49 \times 10^7 \text{ m s}^{-1}$
(b) $6.21 \times 10^{24} \text{ m}$
6. (a) $2.22 \times 10^7 \text{ m s}^{-1}$
(b) $9.25 \times 10^{24} \text{ m}$

7. (a) 8×10^{-2}
 (b) 410 nm
8. (a) $3.0 \times 10^7 \text{ m s}^{-1}$
 (b) $1.25 \times 10^{25} \text{ m}$, 1.32×10^9 light years
9. $2.27 \times 10^7 \text{ m s}^{-1}$
10. (b) $4.55 \times 10^{14} \text{ Hz}$
11. (a) $1.23 \times 10^7 \text{ m s}^{-1}$
 (b) 542 million light years
12. $1.83 \times 10^6 \text{ m s}^{-1}$
13. $3.24 \times 10^{-12} \text{ m}$

Section 7: Big Bang theory

1. (a) P
 (b) Energy emitted increases
 (c) Increases
 (d) (ii) $T \lambda_{\text{max}} = 2.9 \times 10^{-3} \text{ m K}$
 (e) (i) $T = 11,000 \text{ K}$
 (ii) $\lambda_{\text{max}} = 1.3 \times 10^{-7} \text{ m}$
 (iii) $T = 2.6 \text{ K}$
 (iv) $\lambda = 9.5 \times 10^{-6} \text{ m}$, infrared