Higher Grade Physics

OUR DYNAMIC UNIVERSE

Special 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:

   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).

   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

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 $2{\cdot}4 \times 10^8$ ms^{-1}. It sends out a light beam in the forwards direction. Meanwhile another spaceship B is moving towards spaceship A at a speed of $2{\cdot}4 \times 10^8$ ms^{-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 $7{\cdot}5 \times 10^7$ ms^{-1}. It emits a pulse of light when it is $3{\cdot}0 \times 10^{10}$ 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 $1{\cdot}5 \times 10^8$ ms^{-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 ms^{-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) $3{\cdot}0 \times 10^8$ ms^{-1}
    (b) $2{\cdot}0 \times 10^8$ ms^{-1}
    (c) $1{\cdot}5 \times 10^8$ ms^{-1}
    (d) $1{\cdot}0 \times 10^8$ ms^{-1}

Time Dilation

12. 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).

13. 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.

Dilated time	*Proper time*	*Speed of object* / $m\,s^{-1}$
(a)	20 h	$1{\cdot}00 \times 10^8$
(b)	10 year	$2{\cdot}25 \times 10^8$
1400 s	(c)	$2{\cdot}00 \times 10^8$
1.40×10^{-4} s	(d)	$1{\cdot}00 \times 10^8$
84 s	60 s	(e)
21 minutes	20 minutes	(f)

14. 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 $m\,s^{-1}$.

    (a) 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.

    (b) 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.

15. 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.

16. 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.

17. A scientist in the laboratory measures the time taken for a nuclear reaction to occur in an atom. When the atom is travelling at $8{\cdot}0 \times 10^7$ $m\,s^{-1}$ the reaction takes $4{\cdot}0 \times 10^{-4}$ s. Calculate the time for the reaction to occur when the atom is at rest.

18. 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.

19. 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.

20. 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.

Length Contraction

21. 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).

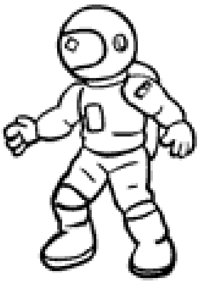
22. In the table shown, use the relativity equation for length contraction to calculate the value of each missing quantity (a) to (f) for an object moving at a constant speed relative to the Earth.

Contracted length	*Proper length*	*Speed of object /* $m s^{-1}$
(a)	5·00 m	$1{\cdot}00 \times 10^8$
(b)	15.0 m	$2{\cdot}00 \times 10^8$
0·15 km	(c)	$2{\cdot}25 \times 10^8$
150 mm	(d)	$1{\cdot}04 \times 10^8$
30 m	35 m	(e)
10 m	11 m	(f)

23. 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 $1{\cdot}8 \times 10^8$ $m s^{-1}$. Calculate the length of the rocket as measured by the observer.

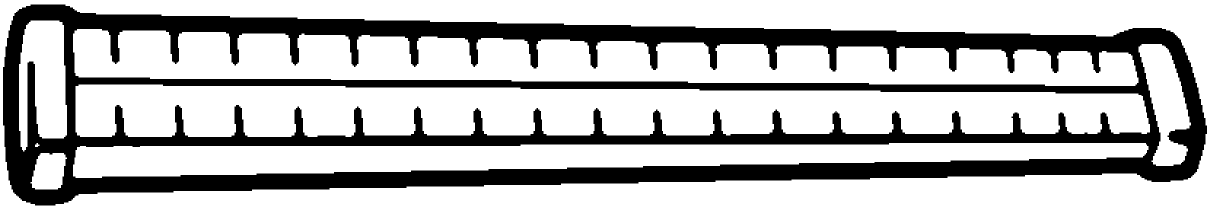
24. A pi meson is moving at 0·90 c relative to a magnet. The magnet has a length of 2·00 m when at rest to the Earth. Calculate the length of the magnet in the reference frame of the pi meson.

25. 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.



26. 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.

27. 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.



28. 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 $m s^{-1}$.

29. 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

30. 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 $1{\cdot}00 \times 10^{-6}$ s.

    (a) Show that the speed of the rocket relative to the Earth is $2{\cdot}40 \times 10^{8}$ m s^{-1}.
    (b) Calculate the time taken, as measured by a clock in the rocket, for the rocket to travel from A to B.
    (c) What is the distance between points A and B as measured by metre sticks carried by an observer travelling in the rocket?

31. A spacecraft is travelling at a constant speed of 0·95 c. The spacecraft travels at this speed for one year, as measured by a clock on the Earth.

    (a) Calculate the time elapsed, in years, as measured by a clock in the spacecraft.
    (b) Show that the distance travelled by the spacecraft as measured by an observer on the spacecraft is $2{\cdot}8 \times 10^{15}$ m.
    (c) Calculate the distance, in m, the spacecraft will have travelled as measured by an observer on the Earth.

32. A pi meson has a mean lifetime of $2{\cdot}6 \times 10^{-8}$ s when at rest. A pi meson moves with a speed of 0·99 c towards the surface of the Earth.
    (a) Calculate the mean lifetime of this pi meson as measured by an observer on the Earth.
    (b) Calculate the mean distance travelled by the pi meson as measured by the observer on the Earth.

33. A spacecraft moving at $2{\cdot}4 \times 10^{8}$ m s^{-1} passes the Earth. An astronaut on the spacecraft finds that it takes $5{\cdot}0 \times 10^{-7}$ s for the spacecraft to pass a small marker which is at rest on the Earth.

    (a) Calculate the length, in m, of the spacecraft as measured by the astronaut.
    (b) Calculate the length of the spacecraft as measured by an observer at rest on the Earth.

34. A neon sign flashes with a frequency of 0·2 Hz.

    (a) Calculate the time between flashes.
    (b) 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.

35. 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.

36. 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.

37. 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.

38. Muons, when at rest, have a mean lifetime of $2{\cdot}60 \times 10^{-8}$ 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.