**COMET BAY COLLEGE**

**Physics Unit 3 & 4 - Task 13**

**Relativity Test**

**Name: SOLUTION Total Marks /53**

**Question 1:**

A passenger on a train is walking at 2.50 m s-1 towards the rear of the train. The train is travelling forward at 15.0 m s-1. Relative to an observer on the ground nearby, what is the speed of the passenger? (2 marks)

speed = 15.0 – 2.50 (1 mark)

= 12.5 ms-1 forward (1 mark including direction)

**Question 2:**

A spaceship travelling at 20% of the speed of light (i.e. 0.2 x c) contains a cube shaped box.



An astronaut floating freely in space outside the spaceship views the box through a window as the spaceship passes and records its dimensions as L, W and H. A passenger on the spaceship records the dimensions of the box as Lo, Wo and Ho.

1. Which of the following options best describes the dimensions of the box as observed by the astronaut outside the spaceship compared to the measurements made by the passenger?
2. L<Lo, W<Wo, H=Ho
3. L>Lo, W=Wo, H=Ho
4. L<Lo, W=Wo, H=Ho
5. L<Lo, W<Wo, H<Ho

**C**

Answer: \_\_\_\_\_\_\_ (1 mark)

1. Explain why you selected your answer. (3 marks)

While the moving astronaut (with the box) will see no change in the length, (1 mark)

A stationary astronaut (watching box go by) will see the length shorten (1 mark)

Width and height will not change (1 mark)

**Question 3:**

[](http://upload.wikimedia.org/wikipedia/commons/1/10/Enterprise_NCC-1701-A.jpg)

# In the science fiction TV series Star Trek, the starship Enterprise is accelerated to speed faster than the speed of light (“warp speed”) for travel between star systems or galaxies. Explain why is it impossible to travel at or faster than the speed of light? (2 marks)

As the velocity of particles approach the speed of light, energy is required to increase the velocity further. Some of this energy is turned into mass requiring even larger amounts of energy to accelerate. (1 mark)

No particle can reach the speed of light as it will gain mass according to the Einstein equation E = mc2. (1 mark)

**Question 4:**

A spacecraft moving at 95% of the speed of light passes the Earth on a journey to the star Lalande 21185 a distance of 8.29 light years.

1. In the frame of reference of the spacecraft what time and spatial measurements of the journey are different compared to those measured by an Earth based observer? (2 marks)

The path length through space is shorter than 8.29 light years.

(length contraction) (1 mark)

Time is moving slower on the Earth (time dilation means observed time between ticks on Earth clocks takes longer) (1 mark)

1. In the frame of reference of the Earth what time and spatial measurements of the journey are different compared to those measured by an observer on the spacecraft? (2 marks)

The path length through space is equal to 8.29 light years.

(no path length contraction although spaceship is shorter in direction of travel) (1 mark)

Time is moving slower on the Spacecraft (time dilation means observed time between ticks on moving clocks takes longer) (1 mark)

1. Is it possible for the spacecraft to travel at the speed of light in the frame of reference of the spacecraft? Explain briefly. (1 mark)

No, according to Einstein’s Special Relativity only electromagnetic radiation can travel at the speed of light (in a vacuum). (1 mark)

**Question 5:**

The Andromeda galaxy is receding from Earth at about 0.3*c* (*c* = speed of light). In the search for extra-terrestrial life, a radio signal is sent from Earth into space. At what speed is the radio signal received on Andromeda? Explain your answer. (2 marks)

Arrives traveling at 3 x 108 m s-1  (1 mark)

According to Einstein’s theory of special relativity the speed of light in a vacuum is constant no matter what is the frame of reference. (1 mark)

**Question 6:**

In the science fiction series Star Trek, Captain Kirk orders the starship Enterprise to travel from Earth on a rescue mission to Alpha Centauri (4.2 light-years away). Due to battle damage, the fastest speed that the Enterprise can travel at is just below the speed of light. The crew includes twins and while one of two identical twins is on the mission to Alpha Centauri the other remains on Earth.

1. The Enterprise can only manage a speed of 0.98*c* (*c* = speed of light). At this speed, how long will the starship take to travel to Alpha Centauri and return as seen from Earth?

t = =

At 0.98c 8.4 ÷ 0.98 = 8.572 years (1 mark)

t = 2.71 × 108 s

(2 marks)

1. For the crew on board, what appears to be the time taken to travel to Alpha Centauri and return? (2 marks)

(1 mark)

= 1.706 years (1 mark)

t0 = 5.38 × 107 s

1. On the return to Earth the twins are no longer the same age, one is older. Which twin has aged more and by how much? (2 marks)

The Earth twin is older. (1 mark)

The age difference is 8.572 – 1.706 = 6.866 years. (1 mark)

= 2.17 × 108 s

**Question 7:**

A rigid **1 metre** wooden plank of mass 2.5 kg is attached to a wall by a pivot and is supported by a rope in tension. A 3.5 kg bowling ball is suspended from the plank, as shown below.

Bowling ball

Pivot

Plank

Rope

The diagram is to scale. **Estimate** the tension in the rope. Express your answer to an appropriate number of significant figures. (5 marks)

Length of plank = 1.00 m = lever arm to rope

lever arm to ball = 0.750 m

lever arm to plank CofM = 0.500 m

(1 mark for lever arm to ball and toCoM of plank)

θrope = 30.0° (1 mark) (or other reasonable estimates)

θplank = θball = 90.0° moment = r.F.sin θ

Σacwm = Σcwm about pivot

rrope.Ftension.sin 30° = rball.Fball.sin 90° + rplank.Fplank.sin 90°

1\*Ftension\*0.5 = 0.75\*3.5\*9.8 + 0.50\*2.5\*9.8 (1 mark)

Ftension = 75.95 (1 mark)

= 76 N (appropriate sig figs (1 mark))

**Question 8:**

Classify the following spectra by circling two (2) of the options beneath each description:

1. The flame of a burning candle (1 mark)

Emission Absorption Line Broadband Continuous

1. Light shining from a mercury vapour lamp (1 mark)

Emission Absorption Line Broadband Continuous

1. Light after white light was passed through a solution of Potassium Permanganate (1 mark)

Emission Absorption Line Broadband Continuous

**Question 9:**

An astronaut flies past a stationary observer at a constant 85% of the speed of light. His spacecraft has light A at the front and light B at the rear. The stationary observer sees the two lights A and B illuminate simultaneously. The astronaut sees one light illuminate before the other one.

0.85 c

Light B

Light A

Stationery observer

Astronaut

1. From the frame of reference of the astronaut explain the order of the lights going on.

(2 marks)

The astronaut sees the sequence of A then B and concludes that A illuminated first because both path lengths were equal (1 mark)

and according to Einstein’s special relativity the speed of light is constant in any reference frame. (1 mark)

(Additional info but not required. The simultaneity of events is different. The observer predicts that the astronaut will see A then B because light from B has to travel further to catch up with moving astronaut. Both are correct in their own frame of reference.)

1. The astronaut and the observer both have identical stopwatches set to countdown from one minute. As the astronaut passes the observer both stopwatches commence their countdown. The astronaut states that his stopwatch will finish the countdown first but the observer states the opposite. Explain who is correct and why. (2 marks)

The observer sees the astronaut moving close to speed of light and concludes that the time between the astronaut’s ticks takes longer on the moving clock – so effectively the rate of time passing slows down.

In the frame of reference of the astronaut the observer is moving so the observer’s clock will take longer than the astronaut’s countdown. (1 mark)

Both are correct in their own frame of reference (1 mark)

1. The stationary observer has previously seen the spacecraft from the same distance when it was at rest. He remarks that it seems smaller when it flies past him at 85% the speed of light. Explain in which way the spacecraft seems smaller and also in which way it has retained the same dimensions. (2 marks)

The dimension of length of the object in its direction of travel is contracted (smaller) in the reference frame of the observer. (1 mark)

The dimensions of width and height are unaltered. (1 mark)

**Question 10:**

Particle physics is the modern version of the age old quest – to find the smallest particles that cannot be broken down. Particle accelerators are the ‘laboratory equipment’ in this area of study. Charged particles can be accelerated in two senses – by their change of direction in circular paths or by increasing their speed. Studies can be made on the radiation that they emit whilst being accelerated or the after effects of collisions between high speed particles.

The **cyclotron** first came into use in 1928 using a combination of magnetic and electric fields to accelerate particles in a spiral path. Development of this technology led to the **synchrotron** which uses an evacuated circular tube with many magnets placed around its circumference. As particles are accelerated the electric field is adjusted and the strength of the magnets is increased to maintain a constant radius and compensate for relativistic effects that become important at high particle energies.

Any charged particle that accelerates will radiate electromagnetic energy. This is true even at a constant speed in a circular path. So a continual supply of energy is required in synchrotrons to just maintain a constant particle speed let alone increase their speed. The emitted radiation is known as **synchrotron radiation** and can cover the entire electromagnetic spectrum.

**Linear accelerators (LINAC)** use a straight path and a series of accelerating voltages as the particles move along the line. LINACs are often used to provide the early stages of acceleration before particles are fed into large synchrotrons.

**Collider experiments** take two beams of particles that have been separately accelerated in opposite directions and smash them into each other. This is difficult to achieve but if successful it is an efficient use of energy.

When two particles with an equal magnitude of momentum collide head on, the total momentum is zero before and after the collision. If particles are stationary after the collision then their kinetic energy is zero. By the conservation of energy and mass principle, the energy before the collision is transformed into the mass of new particles formed in the collision. The particles that are present after a collision reaction can be different to those that went in. This is exactly what particle physicists aim to achieve and the discovery and study of these new particles underpins their work.

Every collision is governed by one of the **fundamental forces** (except the force of gravity which has no significant influence on such tiny particles in this context):

* The **electromagnetic** **force** leads to simple collisions between charged particles. No new particles are formed when this force is at work. e.g. 
* The **strong force** dominates reactions between hadrons (which contain quarks). e.g.
* The **weak force** is likely to be involved in lepton reactions, especially if one of the leptons is a neutrino. e.g. 

Einstein’s theory of **special relativity** has led us to the idea that the mass of a moving object is not the same as its rest mass (m0). The mass of a moving object cannot be measured directly; it must be calculated from a measurement of momentum and velocity. The relativistic equations for momentum ***p*** and total energy ***E*** are as follows:

  (These equations are only applicable for non-zero mass)

Relativity has also given us the idea of mass-energy equivalence. In Newton’s version of mechanics a lone particle not influenced by gravity or electromagnetism but moving at a given speed could only have a single form of energy – kinetic. At rest it had no energy at all. This is not the case in relativity. The relationship is described by the equation: 

Photons are packets of energy travelling at the speed of light. Surprisingly it has been proved that although photons have zero mass they do have momentum. It can be shown for a photon that

if:  then:  and since  then: 

Particle physics has also proven to be vital in understanding the nature of the universe a few fractions of a second after the Big Bang. The conditions created in the mightiest accelerators are very similar to those that existed when the universe was 10-12 seconds old.

1. In what sense can a particle be accelerated if its speed remains constant? Explain.

(2 marks)

Velocity has magnitude and direction. (1 mark)

If a particle undergoes circular motion, a change in direction is also acceleration. (1 mark)

1. Once a charged particle has been accelerated to a given speed in a circular path, is further energy required to maintain a constant speed? Explain. (2 marks)

Yes it radiates synchrotron radiation (1 mark)

so this energy must be replaced. (1 mark)

1. Can electrons and neutrinos be subject to the strong force? Explain. (2 marks)

No (1 mark)

The strong (nuclear) force only acts between hadrons / nucleons / quarks (1 mark)

1. If neutrinos are involved in a collision reaction why is it unlikely that this was governed by the electromagnetic force? (1 mark)

Because neutrinos have no charge so they are not influenced by the electromagnetic force. (1 mark)

1. If you hit a ping pong ball with a table tennis bat which of the three fundamental forces described governs this collision? Justify your answer. (2 marks)

the electromagnetic force (1 mark)

because he strong force acts within a nucleus; the weak nuclear force is involved with beta decay (1 mark)

(Involves the interaction between like charges within the bat and ball.)

Or other reasonable explanation.

1. Calculate the momentum of a **proton** travelling at 95% of the speed of light. The rest mass of a proton is given in the formula and constant sheet. (3 marks)

 

Substitutes correct values (1 mark)

Correct handling of denominator (1 mark)

p = 1.524 🞩 10-18 (1 mark) (kg m s-1)

Units desirable but not essential

1. The equation for Einstein’s mass-energy equivalence is: 

Show that for a particle at rest this simplifies to *E = m0 .c2* (2 marks)

If v = 0

then  equals zero (applicable as non zero mass) (1 mark)

So  simplifies to E2 = m02.c4

By taking the square root on both sides then E = m0.c2 (1 mark)

1. From the starting point:  show that the momentum of a **photon** with zero mass can be given by  (2 marks)

If  and m0 = 0 then E2 – p2c2 = 0 (1 mark)

So E2 = p2c2

p2 = E2 / c2

Square root of both sides gives  (1 mark)

(A photon has zero mass so  does not apply to it.)

1. Calculate the momentum of a photon of 550 nm yellow light. (2 marks)

Using the equation: , then  (1 mark)

p = 1.20545 🞩 10-27 (kg m s-1 ) (1 mark)

Units desirable but not essential