**Rossmoyne Senior High School Physics Unit 3 and 4 2021 SOLUTIONS**

**Period Zero Test 4: Special Relativity and the Standard Model**

**Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Score: \_\_\_\_\_\_\_\_\_ /40**

**Time:** 45 min + 5 min reading

**Materials Provided:** This Question/Answer Booklet and the Formulae and Data Booklet

**Instructions:** When calculating numerical answers, show your working or reasoning clearly and include appropriate units. Give final answers to **three** significant figures or other if specified. When estimating numerical answers, give final answers to a maximum of **two** significant figures.

1. On the axes below, the length of an object as a function of velocity according to classical theory is shown. Sketch in the relativistic length as a function of velocity. [2 marks]

0 0.25 0.50 0.75 1.00 1.25 1

curve following classical line at low velocity 1

curve tending to zero at v/c=1 1

1. The first postulate of special relativity states that all inertial frames are equivalent.
   1. Describe the requirements for a frame to be inertial. [1 mark]

A frame that is not undergoing acceleration/maintains a constant velocity 1

* 1. An observer on a train sees a car on the freeway. The car is observed to be at rest relative to the train. Justify whether you can confidently claim the car is an inertial frame or not. [3 marks]

It is not possible to claim whether the car is an inertial frame or not. 1

If the train is accelerating, observing the car at rest would mean the car is accelerating too – not an inertial frame. 1

If the train is an inertial frame/has a constant velocity, the car would be as well.

**OR**

The car has a constant velocity/is at rest making it an inertial frame

(follow through if assumed no acceleration was possible) 1

1. An astronaut making her way from Mars to Pluto observes the distance between the planets to be 0.25 light years. An observer on Mars measures the astronaut's speed as 0.70c.
   1. How long will the astronaut observe the journey to take in years? [2 marks]

2

Students may also determine distance covered in m ()

Then find time ( s) then convert to years.

* 1. Calculate the time of the journey as measured by an observer on Pluto. [2 marks]

Time determined in part (a) is the proper time of the journey. Find dilated time.

2

1. A proton is confined within a synchrotron that has a 250 m radius and a 3.26 × 10-2 T field.
   1. Show that the proton has a momentum of 1.30 × 10-18 kg m s-1. [2 marks]

Rearranges for “mv” 1

1

* 1. Thus, determine the velocity of the proton. [3 marks]

1

(OR ) Correctly rearranges for v, 1

1

1. An ion wind is receding (moving away) at 0.30c from the perspective of a spacecraft. This spacecraft had taken off from a planet to move directly away from the ion wind. The planet based observatory monitors the spacecraft moving away at 0.70c. What velocity does the planet observatory observe the ion wind to have? [5 marks]

Ion wind

Planet

Spacecraft

1 for correct equation

2 for correct u' & v (including negative sign)

towards planet 1 for magnitude

1 for direction

Note: it is possible to use the other relativistic velocity equation if students reinterpret the velocities from the question. Which velocity is positive and negative can vary based on choice of direction convention.

1. An observer watches a ball moving at 60.0 % of the speed of light between two parallel panels at an angle as shown in the diagram.

35.00

1. Does the observer record a proper or dilated time for the ball moving between the plates? Justify your choice. [2 marks]

Dilated time 1

The observer sees the ball in motion and thus all ball events are dilated/The ball is at rest with the event and has the proper time. 1

1. Argue whether changing the angle shown in the diagram would have effect on the **perpendicular** distance between the plates, when observed within the ball's frame of reference. [3 marks]

Identifies length contraction occurs parallel with velocity 1

Identifies the angle influences the component of the velocity perpendicular to the plates 1

Hence, justifies from ball’s perspective the distance between the moving plates depends on this angle. 1

1. In an atom, there is a delicate balance between the forces that hold it together and that try to blow it apart. Complete the table with the appropriate missing terms. [4 marks]

|  |  |  |
| --- | --- | --- |
| Force of | Name of force | Mediating particles |
| Attraction between electrons and the nucleus | Electromagnetic Force | Photons |
| Repulsion between protons | Electromagnetic Force | Photons |
| Attraction between protons and neutrons | Strong Nuclear Force  (residual force) | Gluon (Mesons/Pions) |
| Attraction between protons | Strong Nuclear Force  (residual force) | Gluon  (Mesons/Pions) |

1. Use the table below to assist with your answers to the following questions.

|  |  |  |  |
| --- | --- | --- | --- |
| **Quark** | **Relative Electric Charge** | **Strangeness** | **Bottomness** |
| Up | +2/3 | 0 | 0 |
| Down | -1/3 | 0 | 0 |
| Top | +2/3 | 0 | 0 |
| Bottom | -1/3 | 0 | -1 |
| Charm | +2/3 | 0 | 0 |
| Strange | -1/3 | -1 | 0 |

Note that antiquarks have equal but opposite sign for electric charge, strangeness and bottomness

* 1. Give the quark composition of a baryon that has a +1 electric charge, -1 strangeness and 0 bottomness. [2 mark]

ucs / tus/ ccs, etc.…. Needs **one** strange and then any combination of u,t or c

any for 2

May also describe in words

Gives an incorrect **3** **quark** combination; 1 mark

* 1. Give the quark composition of an antibaryon that has a +1 electric charge, 0 strangeness and +2 bottomness. [2 mark]

2

May also describe in words

Gives an incorrect **3 antiquark** combination; 1 mark

* 1. Give the quark composition of electrically neutral meson that has a +1 strangeness and 0 bottomness. [2 mark]

2

May also describe in words

Gives an incorrect quark-antiquark combination; 1 mark

1. In addition to the energy-mass equivalence described in special relativity, an energy-momentum equivalence was established:

This relationship is consistent with Einstein’s energy-mass relationship.

This relationship shows that even massless particles (), such as light, have an intrinsic momentum () because of their energy content (). Maybe surprisingly, the momentum of light was theorised and experimentally confirmed before Einstein's theory of special relativity and was used as the basis for de Broglie's work on the wave nature of matter.

There are also similarities between this energy-momentum equation and Pythagoras' theorem. The square of the energy content of a particle is equal to the sum of the squares of the rest energy and the value of .

1. Using the energy-momentum relationship, show that the expression for the momentum of a photon of light as a function of its frequency, , is . [2 marks]

, setting

1

1

1. Find the momentum of a 1.50 × 1015 Hz photon. [1 mark]

1

1. The two right angled triangles shown below represent the energy-momentum equation. Each triangle is for the same particle but at different velocities. Label the three sides of each triangle with its value (, or ). [2 marks]

Slow particle

Fast particle

1 mark for having E on hypotenuse of both triangles

1 mark for having pc along horizontal side of both triangles and along vertical side.