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Mahindra University Hyderabad

École Centrale School of Engineering

M-1 ~~End Semester~~ Examination

Program: B. Tech **Branch: CSE/ARI/CAM/ECM/ECE** **Year: III** **Semester: 2**

Subject:- An introduction to Spacetime Physics (PH3203)

Date: 06/03/2025 **Start Time: 04:45 PM**

Max. Marks: 40 marks **End Time: 06:00 PM**

Instructions:

- Answer all the questions.
- All the best!

Section-I : MCQs. Please explain your answers. (15 marks)

Q1: **(2 + 1 = 3 M)**

One morning you woke up inside a sealed capsule drifting in deep space, with no windows or external references. To determine whether your reference frame is truly inertial, you conduct a series of experiments. Which of the following observations would reveal that your frame is non-inertial?

(a) A ball released from rest remains exactly where it was placed.

(b) A pendulum, once set in motion, swings symmetrically back and forth.

(c) A dropped object appears to accelerate in a curved path without any apparent force acting on it.

(d) You feel weightless and float freely inside the spaceship.

Q2: **(2 + 1 = 3 M)**

Which of the following physical quantities remain invariant under Galilean transformation?

(a) Velocity and time

(b) Acceleration and time

(c) Distance and velocity

(d) Momentum and kinetic energy

Q3: **(2 + 1 = 3 M)**

Since the separation distance between two events is invariant under Galilean transformations, which of the following statements about forces is correct?

(a) Gravitational and electrostatic forces are invariant, but magnetic forces are not.

(b) All fundamental forces remain invariant under Galilean transformations.

(c) Only contact forces, such as friction and normal force, are invariant.

(d) Magnetic and electric forces are both invariant under Galilean transformations.

Q4: **(2 + 1 = 3 M)**

A spaceship moves at a constant velocity v ($v \sim c$) relative to an observer on Earth. Inside the spaceship, two clocks—one at the front and one at the rear—are synchronized in the spaceship's rest frame using Einstein's light signal method. From the perspective of the Earth observer, which of the following statements about the clocks' synchronization is correct?

(a) The clocks remain synchronized in all reference frames since time is absolute.

(b) The clock at the front lags behind the clock at the rear by an amount $\Delta t = vL/c^2$ due to the relativity of simultaneity.

(c) Both clocks appear to run slower due to time dilation, but they remain synchronized in the Earth observer's frame.

(d) The clock at the front shows a later time than the rear clock because the spaceship is moving.

Q5: **(2 + 1 = 3 M)**

Maxwell's equations predict that electromagnetic waves propagate at a constant speed c, independent of the motion of the source. This prediction created a fundamental conflict with classical mechanics. What was the precise nature of this conflict?

(a) The wave equation implied that the speed of light should change in different inertial frames, but experiments showed it remained constant.

(b) The invariance of the speed of light under Maxwell's equations was incompatible with Galilean transformations, which assume simple velocity addition.

(c) Maxwell's theory required a medium (the ether) for wave propagation, but special relativity later proved that ether must be at absolute rest.

(d) According to Newtonian mechanics, the motion of a charged particle should not produce self-sustaining waves in free space, contradicting Maxwell's predictions.

Section-II : Answer all the questions (25 marks)

Q6: **(4 + 4 = 8M)**

(a) Two astronauts are playing a game of billiards inside a spaceship moving with a constant velocity v ($v \sim c$) relative to an observer on Earth. The astronauts observe that momentum is conserved when the billiard balls collide on their table. Now, suppose that during the collision, one of the balls loses a small amount of mass due to surface chipping, which is common in microgravity environments. Analyze whether momentum remains conserved for the Earth observer. Show that for momentum to be conserved in the Earth frame, mass conservation must hold within the spaceship.

(b) A π^+ meson is created in a high-energy collision of a primary cosmic-ray particle in the earth's atmosphere 200 km above sea level. It descends vertically at a speed of 0.99c and disintegrates, in its proper frame, 2.5×10^{-8} sec after its creation. At what altitude above sea level is it observed from earth to disintegrate?

Q7: **(4 + 4 = 8 M)**

The radius of milky way galaxy is 3×10^{20} m, or about 3×10^{4} light-years.

(a) Can Mr. Balayya, **in principle**, travel from the center to the edge of our galaxy in a normal lifetime? Explain, using either time-dilation or length-contraction arguments.

(b) What constant velocity would he need to make the trip in 30 years (proper time)?

Q8: **(2 + 3 + 4 = 9 M)**

A pilot is supposed to fly due east from A to B and then back again to A due west. The velocity of the plane in air is u and the velocity of the air with respect to the ground is v (where $v < u$). The distance between A and B is l and the plane's air speed u is constant. (Hint : Analogous to the Michelson-Morley experiment)

(a) If $v = 0$ (still air), show that the time for the round trip is $t_0 = \frac{2l}{u}$.

(b) Suppose that the air velocity is due east (or west). Show that the time for a round trip is then

$$t_F = \frac{t_0}{1 - \frac{v^2}{(u)^2}}.$$

(c) Suppose that the air velocity is due north (or south). Show that the time for a round trip is then

$$t_N = \frac{t_0}{\sqrt{1 - \frac{v^2}{(u)^2}}}.$$