Queen Mary
University of London

BSc/MSci Examination by course unit

Wednesday 20th May 2009 10:00 - 12:30

PHY116 From Newton to Einstein Duration 2 hours 30 minutes

YOU ARE NOT PERMITTED TO START READING THIS QUESTION PAPER UNTIL INSTRUCTED TO DO SO BY AN INVIGILATOR.

Answer **ALL** Questions in **Section A** and **TWO** Questions in **Section B**. Section A carries 40 marks and each question in Section B carries 30 marks.

CALCULATORS ARE PERMITTED IN THIS EXAMINATION. PLEASE STATE ON YOUR ANSWER BOOK THE NAME AND TYPE OF MACHINE USED.

COMPLETE ALL ROUGH WORKINGS IN THE ANSWER BOOK AND CROSS THROUGH ANY WORK WHICH IS NOT TO BE ASSESSED.

CANDIDATES SHOULD NOTE THAT THE EXAMINATION AND ASSESSMENT REGULATIONS STATE THAT POSSESSION OF UNAUTHORISED MATERIALS AT ANY TIME WHEN A CANDIDATE IS UNDER EXAMINATION CONDITIONS IS AN ASSESSMENT OFFENCE. PLEASE CHECK YOUR POCKETS NOW FOR ANY NOTES THAT YOU MAY HAVE FORGOTTEN THAT ARE IN YOUR POSSESSION. IF YOU HAVE ANY THEN PLEASE RAISE YOUR HAND AND GIVE THEM TO AN INVIGILATOR NOW.

EXAM PAPERS CANNOT BE REMOVED FROM THE EXAM ROOM.

Examiners: Prof. D.J. Dunstan and Dr T. Kreouzis

SECTION A: ANSWER ALL QUESTIONS

A1. State, giving reasons, whether the following quantities are scalars or vectors:

(a) (x, y, z)

(b) $(\mathbf{u} + \mathbf{v} + \mathbf{w})$

(c) $(1,0,0) \times (1,1,0)$

(d) $\hat{\mathbf{i}}.\hat{\mathbf{k}}$ **[4]**

A2. (a) State Newton's Second Law of Motion and explain what it says about momentum.

(b) Give the vertical momentum of a bungee jumper weighing 80kg, one second after jumping (neglect air resistance and assume the bungee is not yet taut). **[4]**

A3. A ramp is at 30° to the horizontal, and a 10 kg mass is stationary on it, held by friction.

(a) Indicate on a sketch the force exerted by the ramp on the mass; resolve it into horizontal and vertical components and give their values.

(b) On a new sketch, resolve the force exerted by the ramp on the mass into components parallel and perpendicular to the ramp and give their values.

(c) What is the minimum coefficient of friction between the mass and the ramp? **[4]**

A4. A cyclist following the route of the Tour de France starts from the valley at 800m altitude and climbs to the Col de Galibier at 2800m. She and her bicycle weigh altogether 90kg.

(a) How much gravitational potential energy does she gain?

(b) If she does the climb in 6 hours 15 minutes, what power has she been generating?

(c) Neglecting air resistance and assuming she doesn't use the brakes, on descending, at what speed would she reach the valley? **[4]**

A5. A light stick of length 1 m has point masses of weight each 2 kg at the two ends and at the centre.

(a) Calculate its Moment of Inertia *I* about an axis perpendicular to the stick and passing through the centre.

(b) Calculate its Moment of Inertia *I* about an axis perpendicular to the stick and passing through one end.

(c) Show that your answers for (a) and (b) are consistent with the Theorem of Parallel Axes. **[4]**

A6. A stationary flywheel of mass 10kg has all its mass at the rim at 20 cm radius from its axis.

(a) Calculate its moment of inertia

(b) If a torque of 20 Nm about the axis is applied for 10 s, what speed does it rotate at?

(c) What is now its rotational kinetic energy?

(d) What is its angular momentum? **[4]**

A7. Derive Kepler's Third Law ($T^2 \propto r^3$) for a planet in a circular orbit in an inverse-square law gravitational field. **[4]**

A8. A mu-meson at 0.99*c* travels from its creation in the upper atmosphere at 55km altitude to its decay at the surface of the Earth.

(a) Calculate the value of γ needed for analysis of this.

(b) How far has the surface of the Earth travelled towards the mu-meson in the frame of reference of the mu-meson?

(c) How long did the mu-meson live from creation to decay in the Earth's frame of reference?

(d) How long did the mu-meson live from creation to decay in the mu-meson's frame of reference? **[4]**

A9. Taking the speed of light $c = 1$, consider two events occurring at the coordinates $(x, y, z, t) = (0, 0, 0, 0)$ and $(2, 0, 0, 1)$ in a frame **S**.

(a) What is the interval (frame-invariant distance) between the two events?

(b) Is the interval you obtain in (a) space-like or time-like?

(c) What is the Proper Length or Proper Time between the two events? **[4]**

A10. (a) Given that Principle of Relativity and the Principle of the Constancy of the Speed of Light result in the Theory of Special Relativity, what additional Principle gives rise to the Theory of General Relativity?

(b) What experimental evidence supports the Principle of Relativity?

(c) What experimental evidence supports the Principle of the Constancy of the Speed of Light?

(d) What experimental evidence supports the third Principle mentioned in (a)? **[4]**

SECTION B: ANSWER TWO QUESTIONS

B1. (a) A ladder stands on a floor with a coefficient of friction of $\mu = ½$ and leans against a frictionless wall. The angle the ladder makes to the floor is θ.

(i) Find the minimum value of θ.

(ii) Neglecting the weight of the ladder, what does the minimum value of θ become if a man stands on the top rung (approximate this to the very top) of the ladder?

(iii) An assistant of equal weight now stands on the bottom rung (approximate this to the very bottom), as recommended by Health and Safety procedures. Using your previous results or otherwise, find the minimum value of θ in this situation. **[9]**

(b) A flywheel with a moment of inertia $I = 5$ kg m^2 is mounted on a light axle. It is initially stationary. A torque of 80 Nm is applied to the axle for 25 s.

(i) Calculate the final angular velocity of the flywheel.

(ii) Calculate the final angular momentum of the flywheel.

(iii) Calculate the final rotational energy of the flywheel.

(iv) If a torque of 10 N m is now applied about an axis perpendicular to the axle of the flywheel, what will the motion be? Explain your answer. **[9]**

(c) A proton (rest mass 1.675×10^{-27} kg) has a total energy that is three times its rest energy. Find

(i) The kinetic energy of the proton.

(ii) The magnitude of the momentum of the neutron.

(iii) The speed of the neutron **[12]**

B2. (a) Your garage is a box 2.5 m wide (*x*-direction) by 2 m high (*y*-direction) and 4 m deep (*z*-direction). Your friend is standing by the garage door as you approach in your new car along the *z*-direction at a speed such that the Lorentz factor $\gamma = 2$.

(i) What is your speed?

(ii) What dimensions do you observe the garage to have?

(iii) Your new car is 5m long. What length does your friend observe it to be?

(iv) How long after the front of your car passes the garage door do you observe the front of the car to hit the garage back wall, and the back of the car to pass the garage door?

(v) How long after the front of your car passes the garage door does your friend observe the front of the car to hit the garage back wall, and the back of the car to pass the garage door?

(vi) When the back of the car passes the garage door, your friend closes the garage door. Use your results from parts (i) to (v) to explain whether the car fits in the garage. **[9]**

(b) A child who weighs 20kg sits on a playground swing consisting of a light seat hung by light cords of length 3.6m from a pivot. Her father pushes her too enthusiastically, so that she goes right round, over the top, without the cords becoming slack.

(i) What is her minimum speed at the top?

(ii) Find her speed when she is level with the pivot, and when she passes directly under the pivot, if she went over the top at the minimum speed.

(iii) Find the tension in the cords when she is level with the pivot, and when she passes directly under the pivot, if she went over the top at the minimum speed. **[9]**

(c) The orbital speed of the minor planets in the asteroid belt, which is of radius 2.7 Astronomical Units, is approximately 18 km s^{-1}. A comet is observed to cross the asteroid belt at a speed of 25 km s^{-1}.

(i) What can you say about the shape of the comet's orbit?

(ii) And what could you say if its speed were 26 km s^{-1}?

(iii) If the distance of closest approach of the comet to the Sun is one-ninth of the radius of the asteroid belt, find the speed of the comet there.

(iv) Before the comet became a comet, it was a snowball in a very large circular orbit around the Sun. Making suitable assumptions, estimate the radius of this orbit. **[12]**

B3. (a)

(i) A planet of mass m is in a circular orbit of radius R about a star of mass $M >> m$. Calculate its kinetic energy and its gravitational potential energy (the zero of potential energy is at infinity) and show the relationship between them. Hence or otherwise show that the escape velocity is $\sqrt{2}$ times the orbital velocity.

(ii) An empty wooden barrel (with no end covers) weighs 5 kg. If it rolls along the pavement at 2 ms^{-1} what is its total kinetic energy (translational plus rotational)?

[10]

(b) Given a pair of events that occur, one at the origin of an inertial frame, coordinates (0, 0, 0, 0), and the other at (x, y, z, t) in the same frame, explain using examples:

(i) What is meant by the Proper Length Interval between them?

(ii) What is meant by the Proper Time Interval between them?

(iii) Under what conditions can the events be simultaneous in some inertial frame?

(iv) Under what conditions can the events occur in the same place in some inertial frame?

(v) Can the pair of events have both a proper time interval and a proper length between them? **[10]**

(c) A ladder placed horizontally and supported at the two ends bends (deflects) 4cm when a man stands on the middle rung. Calculate the deflection if the ladder is placed against the wall and the same man stands on the same middle rung

(i) If the ladder is at 45º to the floor, and

(ii) If the ladder makes the recommended angle of about 80º to the floor. **[10]**

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