Queen Mary
University of London

BSc/MSci Examination by course unit

Friday 28th May 2010 14:30 - 17:00

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 50 marks and each question in Section B carries 25 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.

Useful information:

$g = 9.81\,\mathrm{ms^{-2}}$ $c = 3\times10^{8}\,\mathrm{ms^{-1}}$ $R_{earth} = 6.37\times10^{6}\,\mathrm{m}$ $M_{earth} = 5.97\times10^{24}\,\mathrm{kg}$ $m_{electron} = m_{positron} = 0.511\,\mathrm{MeV/c^2}$

$G = 6.67\times10^{-11}\,\mathrm{Nm^2kg^{-2}}$ $I_{solid\ cylinder} = \dfrac{MR^2}{2}$ $I_{solid\ sphere} = \dfrac{2MR^2}{5}$

$\mathbf{u.v} = u_x v_x + u_y v_y + u_z v_z$ $\mathbf{u}\times\mathbf{v} = \left\{(u_y v_z - u_z v_y)\hat{i} + (u_z v_x - u_x v_z)\hat{j} + (u_x v_y - u_y v_x)\hat{k}\right\}$

Examiners: Dr T. Kreouzis and Dr A.J.Martin

SECTION A: ANSWER ALL QUESTIONS

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

(a) $\hat{i}+2\hat{j}-\hat{k}$

(b) $|\hat{k}|$

(c) $\underline{u}$

(d) $\vec{u}\cdot\vec{v}$

(e) $\vec{u}\times\vec{v}$ [5]

A2. (a) Define linear momentum.

(b) State Newton's second law of motion in terms of linear momentum.

(c) Define an impulse in terms of force and other quantities.

(d) Express the translational kinetic energy in terms of linear momentum. [5]

A3. A body moves along a curved path with instantaneous speed v.

(a) What is the direction of v?

(b) Give an expression for the tangential acceleration.

(c) Give an expression for the radial acceleration. [5]

A4. An object rests on a rough inclined plane, the coefficient of friction between the surfaces is μ.

(a) Write an expression for the frictional force acting on the object if it is at rest.

(b) What is the frictional force if the object is sliding?

(c) If the object has mass m and the plane is inclined at θ to the horizontal, calculate its acceleration as it slides down the plane. [5]

A5. A rigid body is composed of several point masses and rotates at angular velocity, $\underline{\omega}$, about an axis passing through its centre of mass.

(a) Define the moment of inertia, I, of the object.

(b) Define the angular momentum of an individual point mass.

(c) Write an expression relating the total angular momentum of the object, $\underline{L}$, to the moment of inertia of the body.

(d) Define the rotational kinetic energy of the object in terms of $\underline{L}$. [5]

A6. Two point masses, m_1 and m_2 are a distance r apart.

(a) Write an expression for the gravitational force between them.

(b) Write an expression for the gravitational potential energy of the pair.

(c) Prove that the speed, v, of a satellite in a circular orbit, radius r, around a body of mass M is given by: $v = \sqrt{\frac{GM}{r}}$ [5]

A7. State Kepler's Laws of planetary motion and explain any simple underlying physical principles. [5]

A8. The theory of special relativity is based on two postulates.

(a) What are these postulates?

(b) The quantities β and γ often appear in relativity; give their usual definitions.

(c) What value does γ take in the limit of classical physics?

[5]

A9. In frame S an event occurs at the coordinates (x, y, z, t). Frame S' moves with velocity v in the positive x-direction relative to frame S and the clocks in both reference frames are synchronised when the origins coincide.

(a) Write the coordinates of the event in S' in terms of its coordinates in S.

(b)What is the interval (frame-invariant distance) between the origin and the event? [5]

A10. The relativistic mass of an object, m, is not the same as its rest mass, m_0.

(a) Write an expression linking m and m_0.

(b) Write an expression for the relativistic kinetic energy, T, of an object in terms of m_0 and other quantities.

(c) Write an expression linking the total relativistic energy of an object, E, to its kinetic energy, T, and other quantities.

(d) Write an expression for the relativistic momentum of an object, p in terms of m_0 and other quantities.

(e) Write an expression linking the total relativistic energy of an object, E, to its momentum, p, and other quantities. [5]

SECTION B: ANSWER TWO QUESTIONS

B1. (a) Consider the vectors $\hat{i}+\hat{j}+\hat{k}$ and $\hat{i}-\hat{j}+\hat{k}$

i) Calculate the dot product of the vectors and hence the angle between them.

ii) Calculate the unit vector in the direction of the cross product of the vectors. [5]

(b) A 1.50kg wooden block rests on a rough horizontal surface. A 10.0 g bullet is fired at 500 ms^{-1} horizontally into the block. The bullet embeds itself into the block and they slide for 1.86m before coming to rest. What is the coefficient of friction between the block and the suface? [7]

(c) Station Alpha (A) and station Beta (B) are 1.00×10^{9} m apart and at rest relative to each other. The two stations emit a synchronisation signal simultaneously in their frame of reference in the form of a 120 μs duration light pulse. Observer W is travelling parallel to AB at a constant speed v.

i) If W measures the distance AB to be 6.00×10^{8} m how fast is she travelling?

ii) What is the synchronisation signal duration according to W?

iii) What is the time difference between the two synchronisation signals being emitted as measured by W?

iv) Station Alpha measures K to be travelling at 0.5 c in the direction BA directly towards W (in a head to head collision arrangement). How fast is K travelling relative to W?

[13]

B2. (a) A pendulum consisting of a mass m attached to a string of length l is released from rest at an angle θ from the vertical. Calculate the tension in the string when the pendulum is at its lowest point of travel. [6]

(b) The acceleration of an object in free fall is given as $\mathbf{a} = -g\hat{j}$. At time $t = 0$ the object is at the origin with a velocity in the x-y plane of magnitude v at an angle θ to $\hat{i}$. By suitable integration, prove that its subsequent position vector, **r**, is given by:

$$\mathbf{r} = vt\cos\theta\hat{i} + \left(vt\sin\theta - \frac{gt^2}{2}\right)\hat{j} \qquad [7]$$

(c) A flywheel consisting of a solid cylinder, whose radius is 10cm and mass 10kg, is mounted horizontally on a light shaft as shown in figure 1. It is hung centrally, supported by two ropes at A and B. A 0.50 Nm torque is then applied to the flywheel for 20 seconds.

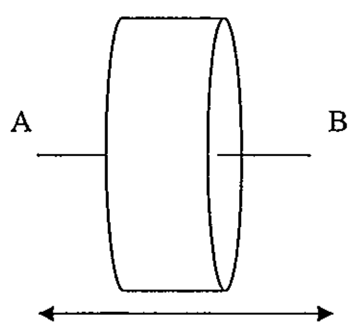

Figure 1: A flywheel mounted horizontally

i) Calculate the angular acceleration of the flywheel while the torque is applied.

ii) Calculate the number of turns the flywheel makes while the torque is applied.

iii) Calculate the final angular momentum of the flywheel.

iv) After the torque is applied, the rope at B is cut. Explain and describe in as much detail as possible the subsequent motion of the flywheel.

[12]

B3. (a) An unstable particle is created in the laboratory and travels at 0.990 c for 1.50 m before decaying.

i) How long does the particle exist for in the laboratory frame of reference?

ii) What is the particle's decay time in its own frame of reference?

iii) How far is the particle expected to travel at 0.990 c before it decays?

iv) How long would an observer travelling in the particle's frame of reference measure the 1.50 m particle track to be? **[5]**

(b) Sputnik-1 was the first man-made satellite to orbit the earth. It travelled in a low eccentricity orbit with a period of 96.2 minutes for several months.

i) Calculate the height above the earth's surface of Sputnik's orbit.

ii) How fast did Sputnik travel? **[8]**

(c) Vector $\vec{b}$ lies in the x-z plane making an angle of 60° with the vector $\vec{a} = \hat{i} + \hat{j}$, it is also perpendicular to the vector $\vec{c} = -\hat{i} - \hat{j} - \hat{k}$. Given that $|\vec{b} \times \hat{j}| = 2$, find $\vec{b}$. [7]

(d) By simple calculation, show that the lower limit for the density of a black hole is inversely proportional to its mass squared. [5]

B4 (a) A solid sphere rolls from rest, without slipping, down a ramp of height h. Calculate its speed at the bottom of the ramp. [6]

(b) An aeroplane flies at constant altitude due South over London. Its speed is 320 km/h and the latitude of London is 51° North. Find the magnitude and direction of the Coriolis acceleration on the aeroplane. [6]

(c) Z^0 bosons are massive elementary particles, their rest mass 91.2 GeV/c^2. Their existence was predicted theoretically before their experimental discovery in February 1983. In an asymetric particle accelerator a beam of 30 GeV (kinetic energy) electrons collides with a beam of positrons, of kinetic energy E_p , moving in the opposite direction. An electron and a positron annihilate to produce a Z^0 boson.

i) Explain why the rest mass of the electron and the positron can be neglected in this problem.

ii) Calculate the positron beam energy E_p.

iii) Calculate the momentum of the resultant Z^0 particle.

iv) Calculate the speed of the Z^0 particle.

[13]

End of Paper