Queen Mary
University of London

BSc/MSci EXAMINATION

PHY-116 Newton to Einstein

Time Allowed: 2 hours 15 minutes

Date: 26th May 2005

Time: 10:00

Answer THREE questions only. Section A contains one question which is COMPULSORY. Attempt two further questions from section B.

Question 1 carries 40 marks, the other questions each carry 30 marks. Indicative marks for the different parts are given by [ ] in bold face.

Data

Gravitational constant	G	6.67×10^{-11}	$N\,m^2\,kg^{-2}$
Speed of light	c	3.00×10^{8}	$m\,s^{-1}$
Mass of sun	M_{sun}	1.99×10^{30}	kg
Distance of earth from sun	1 AU	1.50×10^{11}	m

The use of calculators is permitted

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Section A

Question 1.

(a) A rocket fires two engines simultaneously. One produces a thrust of 725 N directly forward while the other gives a 500 N thrust at 35° above the forward direction. Find the magnitude and direction (relative to the forward direction) of the resultant force which these engines exert on the rocket. **[5]**

(b) The human body can survive a sudden stop if the maximum acceleration is less than 250 m/s^2 (approximately 25*g*). If you are in a car accident with an initial speed of 105 km/h and are stopped by an airbag, over what distance must the airbag stop you if you are to survive the crash? **[5]**

(c) A projectile is launched from the ground at an angle of 60° with respect to the horizontal and with an initial velocity of 40 $m.s^{-1}$. Calculate the maximum vertical height reached by the projectile. How long does it take to reach this altitude? **[5]**

(d) Aircraft experience a lift force that is perpendicular to the plane of the wings and to the direction of flight. A small aircraft is flying at a constant speed of 240 km/h. At what angle from the horizontal must the wings of the aircraft be tilted for the aircraft to execute a horizontal turn with a radius of 1200 m? **[5]**

(e) Small blocks, each with a mass *m*, are clamped at the ends and at the centre of a light rod of length *L*. Calculate the moment of inertia of the system about an axis perpendicular to the rod and passing through a point ¼ of the length from one end. You can ignore the moment of inertia of the rod. **[5]**

(f) A spaceship flies past Mars with a speed of 0.978*c* relative to the surface of the planet. When the spaceship is directly overhead at an altitude of 1200 km, a very bright signal light on the Martian surface blinks on and then off. An observer on Mars measures that the signal was on for 82.4 μs. What is the duration of the light pulse measured by the pilot of the spaceship? **[5]**

(g) A metre stick moves past you at great speed. Its motion relative to you is parallel to its long axis. If you measure the length of the moving stick to be 0.3048 m, at what speed is the stick moving relative to you? **[5]**

(h) A proton (rest mass 1.67×10^{-27} kg) has a total energy that is 4 times its rest energy. What is a). The kinetic energy of the proton? b). The magnitude of the momentum of the proton? c). The speed of the proton? **[5]**

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Section B

Question 2.

(a) State Kepler's laws of planetary motion. Show how, in the special case of circular orbits, the third law can be derived from the properties of circular motion and Newton's law of gravity. **[10]**

(b) Saturn has an approximately circular orbit and it takes 29.5 Earth years to make one complete orbit. Calculate the radius of Saturn's orbit. **[7]**

(c) A spaceship orbits a planet in a circular orbit with a velocity, v_0. By considering its total energy, show that in order to escape from the planet it needs to increase its velocity by a factor of at least $\sqrt{2}$. **[7]**

(d) Comets travel around the sun in elliptical orbits with large eccentricities. If a comet has a speed of 2.0×10^4 m.s^{-1} when at a distance of 2.5×10^{11} m from the centre of the sun, what is its speed at a distance of 5.0×10^{10} m? **[6]**

Question 3.

(a) Let O be an inertial reference frame and O' be a frame which is rotating with respect to O with a constant angular velocity $\vec{\omega}$. Then we have

$$\vec{a} = \vec{a}' + 2\vec{\omega} \times \vec{v}' + \vec{\omega} \times \vec{\omega} \times \vec{r}$$

where $\vec{a}$ is the acceleration of a body as observed in the frame O and $\vec{a}', \vec{v}'$ the acceleration and velocity as observed from the frame O'.

Discuss the meaning of the last two terms on the right-hand side of the equation. **[10]**

(b) The air near the equator is strongly heated by the Sun and rises up to replace the colder air from both the northern and southern hemispheres. From a consideration of the effects due to the Coriolis force, deduce the characteristic wind pattern in the northern hemisphere. Illustrate your answer with suitable diagrams. **[10]**

(c) It is often said that water runs down a sink in opposite directions in the northern and southern hemispheres. By considering an ideal circular sink with a radius of 1 m and a hole in the centre, with water flowing radially from the edge to the centre with a constant velocity of 1 m.s^{-1}, estimate the maximum deflection the water will achieve. On the basis of this state whether you think the effect actually occurs. **[10]**

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Question 4.

(a) State the two postulates of Special Relativity. **[5]**

(b) Consider the example of a train carriage moving with a constant velocity, v, past a stationary observer with a light source on the floor of the carriage shining at a mirror and being reflected back to the source. By comparing the journey of the light beam as viewed by an observer on the train carriage and by a stationary observer, derive the expression for time dilation, **[10]**

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - v^2/c^2}}$$

(c) The term Δt_0 is called the proper time. Give a definition of the proper time. **[5]**

(d) A spaceship passes the Earth at a relative speed of $0.6c$. The instant it passes timers are started both on the Earth and the spaceship. When an observer on the Earth measures that the spaceship has travelled 9×10^7 m past him, what does the timer on the spaceship read? At the instant the timer on the spaceship reads 0.4 s what does the timer on the Earth read? **[10]**

Question 5.

(a) write down expressions for the relativistic total energy (E), mass (m) and momentum (p) in terms of the rest mass (m_0) and velocity (v). Hence show that, **[10]**

$$E^2 = p^2c^2 + m_0^2c^4$$

(b) Find the rest energy of an electron ($m_e = 9.109 \times 10^{-31}$ kg) in Joules and electron volts ($e = 1.602 \times 10^{-19}$ C). Find the speed of an electron which has been accelerated by an electric field, from rest, through a potential difference of 20 kV. **[10]**

(c) A pion (π^+) which is at rest, decays into a muon (μ^+) and a neutrino (ν). The mass of the muon is 106 MeV/c^2 and its kinetic energy is 4.6 MeV. Given that the neutrino has negligible mass find the mass of the pion. **[10]**

End of Examination Paper **Dr W P Gillin**