KEELE UNIVERSITY

LEVEL 1 EXAMINATIONS, 2009

(PRINCIPAL COURSE)

Thursday 22nd January, 16:00–18:00

ASTROPHYSICS/PHYSICS

PHY-10010

MECHANICS, GRAVITY AND RELATIVITY

Candidates should attempt ALL of PARTS A and B, and TWO questions from PART C. PARTS A and B should be answered on the exam paper, PART C should be answered in an answer book which should be attached to the exam paper at the end of the exam with a treasury tag.

PART A yields 16% of the marks, PART B yields 24% and PART C yields 60%.

Figures in brackets [ ] denote the marks allocated to the various parts of each question. Tables of physical and mathematical data may be obtained from the invigilator.

Registration Number ....

A		C1		Total
B		C2		
		C3		
		C4		

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PART A TICK THE BOX BY THE ANSWER YOU JUDGE TO BE CORRECT (MARKS ARE NOT DEDUCTED FOR INCORRECT ANSWERS).

A1 The units of energy are equivalent to:

☐ kg m^{-1} s^{-1} ☐ kg m s^{-1} ☐ kg m^2 s^{-2} ☐ kg m^2 s [1]

A2 A machine does work of 2000 J over a distance of 4 m. The force exerted is:

☐ 500 N ☐ 1000 N ☐ 1200 N ☐ 2000 N [1]

A3 A particle moving with distance $x = \sin t$ has a velocity of:

☐ $t \sin t$ ☐ t^2 ☐ $\cos t$ ☐ $\sin t$ [1]

A4 A 1-kg mass travelling at 2 m s^{-1} collides with a stationary 5-kg mass and sticks to it. After the collision the momentum of the combined mass is (in SI units):

☐ 2 ☐ 6 ☐ 3 ☐ 1 [1]

A5 A particle which starts from rest and moves with acceleration of $a = 3t^2$ has a velocity of:

☐ t^3 ☐ $6t$ ☐ $6t^2$ ☐ $2t^3$ [1]

A6 Power equates to:

☐ Fv ☐ $F\,dx$ ☐ $F\,dt$ ☐ Fa [1]

A7 Angular acceleration, α, is equivalent to:

☐ ωt ☐ $\tau \times t$ ☐ dL/dt ☐ $d^2\theta/dt^2$ [1]

A8 A flywheel revolves 10 times in 10 seconds. Its angular velocity (in s^{-1}) is:

☐ π ☐ $\pi/2$ ☐ 2π ☐ 1 [1]

A9 If the angle turned by a wheel is described by $\theta = 30t^2$ its angular velocity is:

☐ increasing ☐ decreasing ☐ zero ☐ constant [1]

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A10 The torque and angular momentum vectors are:

- ☐ aligned
- ☐ perpendicular
- ☐ opposite
- ☐ at a tangent

[1]

A11 The expression for gravitational potential energy mgh is valid:

☐ always ☐ for small m ☐ for small h ☐ never [1]

A12 Two masses of M and $2M$ are seperated by r. Midway between the masses the gravitational potential is:

☐ $-12GM/r$ ☐ $-6GM/r$ ☐ $-3GM/r$ ☐ $-3GM/2r$ [1]

A13 Relativity derives from the invariance of physical laws with respect to:

☐ time ☐ orientation ☐ motion ☐ location [1]

A14 A light beam travels at c as seen by one observer. As seen by a rocket, travelling at $0.5\,c$ with respect to the first observer, the light beam appears to travel at:

☐ $0.5\,c$ ☐ $c/\sqrt{0.75}$ ☐ $c/(1+0.25)$ ☐ c [1]

A15 A spacecraft's proper length is 8 m. An observer sees its length as 4 m. The spacecraft's velocity is:

☐ $\sqrt{\frac{1}{2}}c$ ☐ $0.5c$ ☐ $\sqrt{\frac{3}{4}}c$ ☐ $\frac{3}{4}c$ [1]

A16 A particle's momentum is given by:

☐ m_0v ☐ βm_0v ☐ γm_0v ☐ γm_0c [1]

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PART B Answer all Eight questions

B1 A car travels at a constant speed, then brakes hard as the driver sees a rabbit, then gradually accelerates again to the previous speed, and continues. Sketch the acceleration, speed and distance travelled as functions of time. [3]

B2 A crane lifts a load of mass 500 kg vertically at a rate of 2 $\mathrm{m\,s^{-1}}$. What is the power exerted by the crane's motor. [Take $g = 9.8\ \mathrm{m\,s^{-2}}$.] [3]

B3 A boy pushes a 50-kg cart up an incline, 30° to the horizontal. What is the minimum force with which the boy needs to push? [Take $g = 9.8\ \mathrm{m\,s^{-2}}$.] [3]

B4 Define the quantity torque. [3]

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B5 If a planet of radius 5000 km has an acceleration due to gravity, g, of 15 m s
its surface, what is its mass? [3]

B6 Which exerts a greater gravitational pull on the Moon, the Earth or the Sun? [Earth's mass: 6×10^{24} kg; Sun's mass: 2×10^{30} kg; Earth–Moon distance: 3.8×10^{8} m; Moon–Sun distance: 1.5×10^{11} m.] [3]

B7 An electron moves so that its total energy is twice its rest-mass energy. What is its speed? [3]

B8 An elementary particle decays after $\tau = 5$ s. It is fired at a speed of 0.999c towards a detector located 10^{10} m away. Will it reach the detector? Justify your answer. [3]

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PART C Answer TWO out of FOUR questions

C1. The kinetic energy of a 100-g particle increases with distance along a track, x, according to $E = 100(1 - e^{-x})$ J.

Sketch the kinetic energy against x. [4]

Find an expression for the force on the particle. [8]

Sketch the force against x. [4]

Find an expression for the acceleration of the particle as a function of x. [3]

Find an expression for the velocity of the particle as a function of x. [8]

What is the velocity of the particle far down the track? [3]

C2. The moment of inertia for a particle is $I = mr^2$ while for an extended body $I = \int r^2\, dm$ (for mass m at a distance r from the axis).

Prove that for a circular disc of mass M and radius R the moment of inertia, about an axis through its centre, is $I = \frac{1}{2}MR^2$. [12]

A 80-kg man stands still on the rim of an initially stationary circular carousel of radius 3 m and mass 200 kg. The man begins to walk at 1 $\mathrm{m\,s^{-1}}$ (with respect to the ground) along the rim. What is his angular velocity, ω? [4]

What is his angular momentum? [4]

What is the angular velocity of the carousel? [5]

How fast is the man walking with respect to the carousel? [5]

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C3. In order to maintain a circular orbit a body must experience a centripetal force of

$$F = \frac{mv^2}{r}$$

where m is the body's mass, v its speed and r the radius of its orbit.

Use the above to show that Newtonian gravity requires that a space-station orbiting a star of mass M has a speed given by $v^2 = \frac{GM}{r}$. [5]

If a non-orbiting particle starts from a very large distance, but then free-falls towards the star, will its speed be faster or slower than that of the space-station at the point when it crosses the space-station's orbit? Justify your answer. [7]

A research space-station orbits a distant star, which has a mass of 5×10^{30} kg, at a distance of 1×10^{11} m. What is its orbital speed? [4]

If this space-station launches a rocket back to Earth, what is the minimum speed (with respect to the space-station) that the rocket needs to have to escape the star's gravity? [10]

In which direction should the rocket be launched? [4]

C4. An alien spacecraft approaches Earth at a speed of $v = 0.9c$. At a distance of 10^{13} m (as measured from Earth) it sends out a laser pulse containing a message announcing its arrival.

How long (as measured from Earth) would the message take to get to Earth? [4]

How long (as measured from Earth) would the spacecraft take to get to Earth after emitting the message? [3]

How long, after receiving the message, would Earth have to prepare for the arrival? [3]

How long after sending the message would the aliens have to prepare for arrival, as they measure it? [10]

The spacecraft continues past Earth at the same speed. One year later, as measured on the spacecraft, it sends another laser message back to Earth. As measured by Earthlings, how long after the fly-by is this message received on Earth? [10]