PH111: Introduction to Classical Physics : Final Examination

Marks: 40 April 20, 2023 (9:30 AM - 12:00)

Note: This exam contains **eight** questions. Marks for each question are written next to it. You have to only write down the final answer on the provided answer sheet, while using other sheets for rough work. These should also be submitted.

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1. Consider a point particle of mass m, lying on a circular, frictionless, horizontal turntable that rotates counter-clockwise about its central axis (along $\hat{z}$) with a constant angular velocity Ω. In a Cartesian coordinate system (x, y, z), rotating with the turntable, with its z axis coinciding with the axis of rotation, calculate the following.

   (a) x and y components of the centrifugal force acting on the particle.

   (b) x and y components of the Coriolis force acting on the particle.

   (c) If there are no external forces acting on the particle, obtain x and y components of the equation of motion for the particle with respect to the rotating frame.

   2+2+1 = 5 marks

2. Consider a particle of mass 1 kg, moving under the influence of a central force $\mathbf{F}(\mathbf{r}) = -\frac{\hat{\mathbf{r}}}{r^3}$.

   (a) Write down the orbit differential equation of this particle in terms of $u = 1/r$ and θ, assuming that its angular momentum $L = 2/\sqrt{3}$ kg-m^2/s.

   (b) Write down the general solution $r(\theta)$ of the differential equation of the previous part.

   3+2 = 5 marks

3. A particle of mass m, under the influence of a central force $\mathbf{F}(\mathbf{r}) = f(r)\hat{\mathbf{r}}$ is seen to move with a constant aerial velocity K, along an orbit whose equation is $r = a(1 + \cos\theta)$, where a is a constant.

   (a) What is the expression for the force $f(r)$?

   (b) What is the total energy of the particle in this orbit?

   3+2 = 5 marks

4. Consider the earth's orbit around the sun to be a circle. The radius of this orbit is defined as 1 AU, the "astronomical unit" of distance. The orbital period of Halley's comet around the sun is approximately 76 years and at its closest approach it is at a distance 0.6 AU from the sun. The masses of the earth and the comet are both negligible compared to the mass of the sun. Using these information calculate the following.

   (a) The distance of the farthest point of the comet's orbit from the sun.

   (b) The ratio of the kinetic energy of the comet between the nearest and farthest points.

   (c) The eccentricity of the comet's orbit correct to *two* decimal places.

   1+2+2 = 5 marks

5. A particle of mass m, thrown up vertically with initial speed v_0, reaches a maximum height and falls back to ground. Assume that the angular speed of rotation of earth is Ω and the angle of latitude of this location is θ in the northern hemisphere. Ignoring the effects due to the centrifugal force, answer the following in terms of v_0, g, Ω, and θ only. Your answer should be in the simplest algebraic form with no unevaluated integrals etc.

   (a) The Coriolis force acting on the particle as a function of time.

   (b) The horizontal component of the velocity when it hits the ground. Is it to the eastwards or westwards?

   (c) What is the distance between the points on earth where the particle was launched and where it hits the ground? Is the deflection to the east or west?

1+2+2 = 5 marks

6. A spaceship moves at speed v, relative to an inertial frame S and fires a rocket in the direction of its motion at a speed v, relative to the spaceship. The pilot of the rocket launches a payload again in the same direction at speed v, relative to the rocket. Using the principles of special theory of relativity, answer the following,

   (a) Determine the speed of the rocket relative to S.

   (b) Determine the speed of the payload relative to S.

2+3 = 5 marks

7. A source located at the origin of an inertial frame S shoots a massless particle at the speed of light c, which travels in a straight line, making an angle of 45^o with respect to the x-axis. Another inertial frame S', is moving with respect to S with a speed $\frac{c}{2}$ along the x-axis.

   (a) Calculate velocity components of the particle, u'_x and u'_y, as observed in S'.

   (b) What would be the corresponding angle as observed in S' ?

   (c) Calculate the value of ${u'_x}^2 + {u'_y}^2$.

3+1+1 = 5 marks

8. Two identical trains of *rest length* L_0 move past each other with velocities $+u$ and $-u$ respectively as observed from an inertial frame S. The time of full crossing is defined as the time interval between the instants when their front of the engines move past each other to the instant when their rear ends move past each other.

   (a) What is the time required for such a full crossing according to an observer in S?

   (b) In a frame attached to one of the trains, how much time would such a full crossing take?

2+3 = 5 marks