Problem 1:

A monoenergetic beam consists of unstable particles with energies 100 times their rest energy. If the particles have rest mass m, their momentum is most nearly

(A) mc
(B) 10 mc
(C) 70 mc
(D) 100 mc
(E) 10^4 mc

Problem 2:

A particle of mass M decays from rest into two particles. One particle has mass m and the other particle is massless. The momentum of the massless particle is

(A) $\frac{(M^2 - m^2)c}{4M}$
(B) $\frac{(M^2 - m^2)c}{2M}$
(C) $\frac{(M^2 - m^2)c}{M}$
(D) $\frac{2(M^2 - m^2)c}{M}$
(E) $\frac{4(M^2 - m^2)c}{M}$

Problem 3:

A meter stick with a speed of $0.8c$ moves past an observer. In the observer's reference frame, how long does it take the stick to pass the observer?

(A) 1.6 ns
(B) 2.5 ns
(C) 4.2 ns
(D) 6.9 ns
(E) 8.3 ns

Problem 4:

A table tennis paddle lies in the x-y plane, as shown. Its center of mass is at the origin of the coordinate system. If I_x, I_y, and I_z are the moments of inertia about the three axes, which of the following is true?

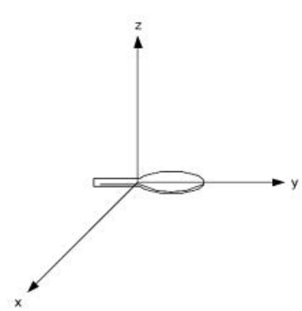
(A) $I_x = I_y = I_z$

(B) $I_x < I_y < I_z$

(C) $I_x < I_z < I_y$

(D) $I_y < I_x < I_z$

(E) $I_z < I_y < I_x$



Problem 5:

Which of the following gives Hamilton's canonical equation(s) of motion? (H is the Hamiltonian, q_i are the generalized coordinates, and p_i are the generalized momenta.)

(A) $q_i = \frac{\partial H}{\partial p_i}, \quad p_i = -\frac{\partial H}{\partial q_i}$

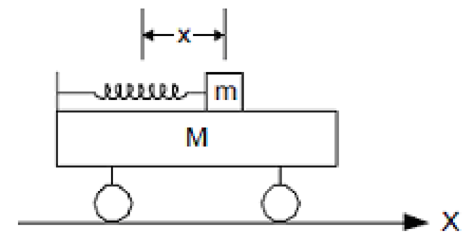
(B) $q_i = \frac{\partial H}{\partial \dot{q}_i}, \quad p_i = \frac{\partial H}{\partial \dot{p}_i}$

(C) $\dot{q}_i = \frac{\partial H}{\partial q_i}, \quad \dot{p}_i = -\frac{\partial H}{\partial p_i}$

(D) $\dot{q}_i = \frac{\partial H}{\partial p_i}, \quad \dot{p}_i = -\frac{\partial H}{\partial q_i}$

(E) $\frac{d}{dt}\left(\frac{\partial H}{\partial p_i}\right) - \frac{\partial H}{\partial q_i} = 0$

Problem 6:



A car of mass M moves horizontally along the X-axis, as shown above. A mass m is attached to the car by a spring having spring constant k. The x-coordinate measures of the position of m; x = 0 corresponds to the position of m in which the spring in neither stretched nor compressed. The axes x and X are parallel.

What is the Lagrangian of this system?

(A) $\frac{1}{2}M\dot{X}^2 + \frac{1}{2}m\dot{x}^2 + \frac{1}{2}kx^2$

(B) $\frac{1}{2}M\dot{X}^2 + \frac{1}{2}m\dot{x}^2 - \frac{1}{2}kx^2$

(C) $\frac{1}{2}M\dot{X}^2 + \frac{1}{2}m(\dot{X}^2 + \dot{x}^2) - \frac{1}{2}kx^2$

(D) $\frac{1}{2}M\dot{X}^2 + \frac{1}{2}m(\dot{X}^2 + 2\dot{x}\dot{X} + \dot{x}^2) - \frac{1}{2}kx^2$

(E) $\frac{1}{2}(M+m)(\dot{X}^2 + \dot{x}^2) - \frac{1}{2}kx^2$

Problem 7:

An electron has total energy equal to four times its rest energy. The momentum of the electron is

(A) $m_e c$

(B) $\sqrt{2}\, m_e c$

(C) $\sqrt{15}\, m_e c$

(D) $4 m_e c$

(E) $2\sqrt{15}\, m_e c$

Problem 8:

Under the influence of a mutual interaction, an object orbits another object that is fixed. The orbits lies in a plane and the areas swept out by the radius vector in equal times are equal. What can be correctly concluded about the force between the objects?

(A) It is central.
(B) It is inverse-square.
(C) It is conservative.
(D) It is gravitational.
(E) None of these conclusions is justified.

Problem 9:

Two spaceships approach Earth with equal speeds, as measured by an observer on Earth, but from opposite directions. A meterstick on one spaceship is measured to be 60 cm long by an occupant of the other spaceship. What is the speed of each spaceship, as measured by the observer on Earth?

(A) $0.4c$
(B) $0.5c$
(C) $0.6c$
(D) $0.7c$
(E) $0.8c$

Problem 10:

Which of the following statements most accurately describes how an electromagnetic field behaves under a Lorentz transformation?

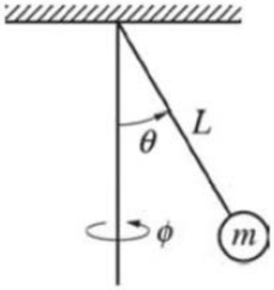
(A) The electric field transforms completely into a magnetic field.
(B) If initially there is only an electric field, after the transformation there may be both an electric and a magnetic field.
(C) The electric field is unaltered.
(D) The magnetic field is unaltered.
(E) It cannot be determined unless a gauge transformation is also specified.

Problem 11:

A beam of muons travels through the laboratory with speed $\upsilon = \frac{4}{5}c$. The lifetime of a muon in its rest frame is $\tau = 2.2 \times 10^{-6}$ s. The mean distance traveled by the muons in the laboratory frame is

(A) 530 m
(B) 660 m
(C) 880 m
(D) 1,100 m
(E) 1,500 m

Problem 12:



A mass m attached to the end of a massless roc of length L is free to swing below the plane of support, as shown in the figure. The Hamiltonian for this system is given by

$$H = \frac{p_\theta^{\ 2}}{2mL^2} + \frac{p_\phi^{\ 2}}{2mL^2 \sin^2\theta} - mgL\cos\theta,$$

where θ and ϕ are defined as shown in the figure. On the basis of Hamilton's equations of motion, the generalized coordinate or momentum that is a constant in time is

(A) θ
(B) ϕ
(C) $\dot{\theta}$
(D) p_θ
(E) p_ϕ

Problem 13:

A mass, m, is attached to a massless spring fixed at one end. The mass is confined to move in a horizontal plane, and its position is given by the polar coordinates r and θ. Both r and θ can vary. If the relaxed length of the spring is s and the force constant is k, what is the Lagrangian, L, for the system?

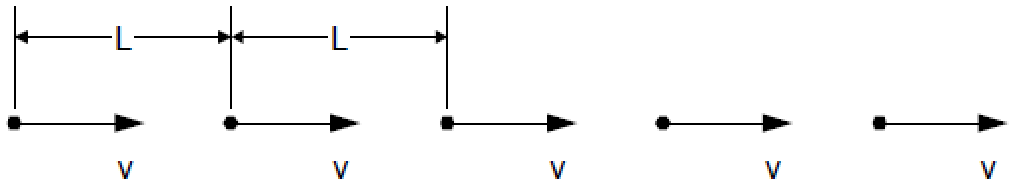
(A) $L = \frac{1}{2}m\dot{r}^2 + \frac{1}{2}mr^2\dot{\theta}^2 - \frac{1}{2}k(r\cos\theta - s)^2$
(B) $L = \frac{1}{2}m\dot{r}^2 + \frac{1}{2}mr^2\dot{\theta}^2 - \frac{1}{2}k(r\sin\theta - s)^2$
(C) $L = \frac{1}{2}m\dot{r}^2 + \frac{1}{2}mr^2\dot{\theta}^2 + \frac{1}{2}k(r - s)^2$
(D) $L = \frac{1}{2}m\dot{r}^2 + \frac{1}{2}mr^2\dot{\theta}^2 - \frac{1}{2}k(r - s)^2$
(E) $L = -\frac{1}{2}m\dot{r}^2 + \frac{1}{2}mr^2\dot{\theta}^2 + \frac{1}{2}k(r - s)^2$

Problem 14:

An observer O at rest midway between two sources of light at $x = 0$ and $x = 10$ m observes the two sources to flash simultaneously. According to a second observer O', moving at a constant speed parallel to the x-axis, one source of light flashes 13 ns before the other. Which of the following gives the speed of O' relative to O?

(A) $0.13c$
(B) $0.15c$
(C) $0.36c$
(D) $0.53c$
(E) $0.62c$

Problem 15:



A steady stream of identical particle, some of which are shown in the figure above, passes an observer O. As measured by O, the particles move with the same relativistic speed v and are spread along a straight line at equal intervals L. Let $\gamma = 1/\sqrt{1 - v^2/c^2}$. The number of particles that pass O in unit time is nearly

(A) $\frac{v}{L}$

(B) $\frac{L}{v}$

(C) $\frac{L}{v\gamma}$

(D) $\frac{v}{L\gamma}$

(E) $\frac{v\gamma}{L}$