Problem 1:

A man of mass m on an initially stationary boat gets off the boat by leaping to the left in an exactly horizontal direction. Immediately after the leap, the boat, of mass M, is observed to be moving to the right at speed v. How much work did the man do during the leap (both on his own body and on the boat) ?

(A) $\frac{1}{2}Mv^2$

(B) $\frac{1}{2}mv^2$

(C) $\frac{1}{2}(M+m)v^2$

(D) $\frac{1}{2}\left(M+\frac{M^2}{m}\right)v^2$

(E) $\frac{1}{2}\left(\frac{Mm}{M+m}\right)v^2$

Problem 2:

A stationary source is producing sound with a frequency f = 500 Hz. The velocity of sound in air is 343 m/s. An observer approaches the source at 20 m/s. What pitch is heard by the observer?

(A) 235 Hz
(B) 472 Hz
(C) 531 Hz
(D) 728 Hz
(E) 610 Hz

Problem 3:

Suppose that the gravitational force law between two massive objects were $\mathbf{F}_{12} = \hat{\mathbf{r}}_{12} G m_1 m_2 / r_{12}^{2+\epsilon}$, where ϵ is a small positive number. Which of the following statements would be FALSE?

(A) The total mechanical energy of the planet-Sun system would be conserved.
(B) The angular momentum of a single planet moving about the Sun would be conserved.
(C) The periods of planets in circular orbits would be proportional to the $(3 + \epsilon)/2$ power of their respective orbital radii.
(D) A single planet could move in a stationary noncircular elliptical orbit about the Sun.
(E) A single planet could move in a stationary circular orbit about the Sun.

Problem 4:

If v is frequency and h is Planck's constant, the ground state energy of a one-dimensional quantum mechanical harmonic oscillator is

(A) 0

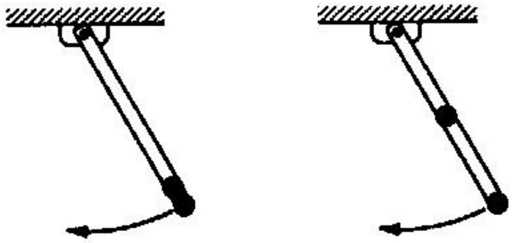
(B) $\frac{1}{3} h v$

(C) $\frac{1}{2} h v$

(D) $h v$

(E) $\frac{3}{2} h v$

Problem 5:



A long, straight, and massless rod pivots about one end in a vertical plane. In configuration I, shown above, two small identical masses are attached to the free end; in configuration II, one mass is moved to the center of the rod. What is the ratio of the frequency of small oscillations of configuration II to that of configuration I ?

(A) $(6/5)^{\frac{1}{2}}$

(B) $(3/2)^{\frac{1}{2}}$

(C) 6/5

(D) 3/2

(E) 5/3

Problem 6:

The wave function of a particle is $e^{i(kx-\omega t)}$, where x is distance, t is time, and k and ω are positive real numbers. The x-component of the momentum of the particle is

(A) 0

(B) $\hbar\omega$

(C) $\hbar k$

(D) $\frac{\hbar\omega}{c}$

(E) $\frac{\hbar k}{\omega}$

Problem 7:

The magnitude of the Earth's gravitational force on a point mass is $F(r)$, where r is the distance from the Earth's center to the point mass. Assume the Earth is a homogeneous sphere of radius R.

What is $\frac{F(R)}{F(2R)}$?

(A) 32
(B) 8
(C) 4
(D) 2
(E) 1

Problem 8:

The magnitude of the Earth's gravitational force on a point mass is $F(r)$, where r is the distance from the Earth's center to the point mass. Assume the Earth is a homogeneous sphere of radius R.

Suppose there is a very small shaft in the Earth such that the point mass can be placed at a radius of $R/2$.

What is $\dfrac{F(R)}{F\left(\frac{R}{2}\right)}$?

(A) 8

(B) 4

(C) 2

(D) $\frac{1}{2}$

(E) $\frac{1}{4}$

Problem 9:

The longest wavelength x-ray that can undergo Bragg diffraction in a crystal for a given family of planes of spacing d is

(A) $\frac{d}{4}$

(B) $\frac{d}{2}$

(C) d

(D) $2d$

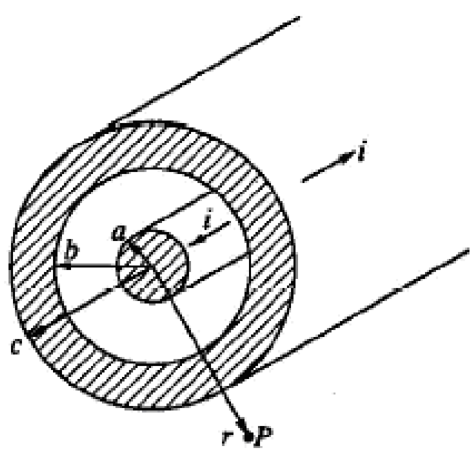
(E) $4d$

Problem 10:

In inertial frame S, two events occur at the same instant in time and $3c \cdot$ minutes apart in space. In inertial frame S', the same events occur at $5c \cdot$ minutes apart. What is the time interval between the events in S'?

(A) 0 min
(B) 2 min
(C) 4 min
(D) 8 min
(E) 16 min

Problem 11:



A coaxial cable having radii $a, b,$ and c carries equal and opposite currents of magnitude i on the inner and outer conductors. What is the magnitude of the magnetic induction at point P outside of the cable at a distance r from the axis?

(A) Zero (B) $\frac{\mu_0 ir}{2\pi a^2}$ (C) $\frac{\mu_0 i}{2\pi r}$

(D) $\frac{\mu_0 i}{2\pi r} \frac{c^2 - r^2}{c^2 - b^2}$ (E) $\frac{\mu_0 i}{2\pi r} \frac{r^2 - b^2}{c^2 - b^2}$

Problem 12:

Listed below are Maxwell's equations of electromagnetism. If magnetic monopoles exist, which of these equations would be INCORRECT?

I. Curl $\mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$

II. Curl $\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$

III. div $\mathbf{D} = \rho$

IV. div $\mathbf{B} = 0$

(A) IV only
(B) I and II
(C) I and III
(D) II and IV
(E) III and IV

Problem 13:

A conducting cavity is driven as an electromagnetic resonator. If perfect conductivity is assumed, the transverse and normal field components must obey which of the following conditions at the inner cavity walls?

(A) $E_n = 0$, $B_n = 0$

(B) $E_n = 0$, $B_t = 0$

(C) $E_t = 0$, $B_t = 0$

(D) $E_t = 0$, $B_n = 0$

(E) None of the above

Problem 14:

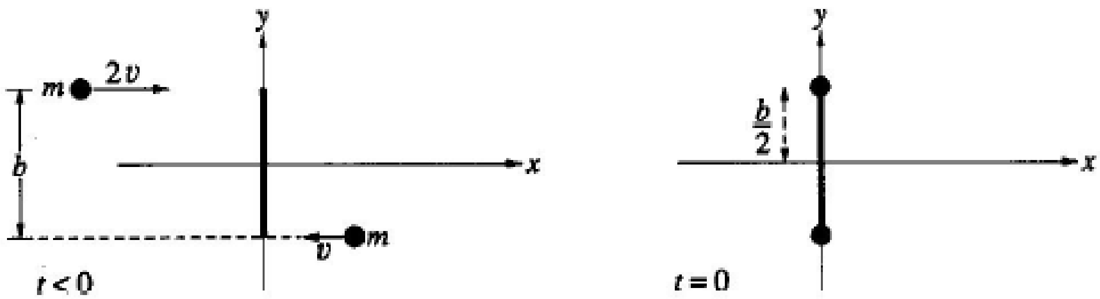


Figure I   Figure II

One ice skater of mass m moves with speed $2v$ to the right, while another of the same mass m moves with speed v toward the left, as shown in Figure I. Their paths are separated by a distance b. At $t = 0$, when they are both at $x = 0$, they grasp a pole of length b and negligible mass. For $t > 0$, consider the system as a rigid body of two masses m separated by distance b, as shown in Figure II. Which of the following is the correct formula for the motion after $t = 0$ of the skater initially at $y = b/2$?

(A) $x = 2vt,\ y = b/2$

(B) $x = vt + 0.5b\sin(3vt/b),\quad y = 0.5b\cos(3vt/b)$

(C) $x = 0.5vt + 0.5b\sin(3vt/b),\quad y = 0.5b\cos(3vt/b)$

(D) $x = vt + 0.5b\sin(6vt/b),\quad y = 0.5b\cos(6vt/b)$

(E) $x = 0.5vt + 0.5b\sin(6vt/b),\quad y = 0.5b\cos(6vt/b)$

Problem 15:

A beam of electrons is accelerated through a potential difference of 25 kilovolts in an x-ray tube. The continuous x-ray spectrum emitted by the target of the tube will have a short wavelength limit of most nearly

(A) 0.1 Å

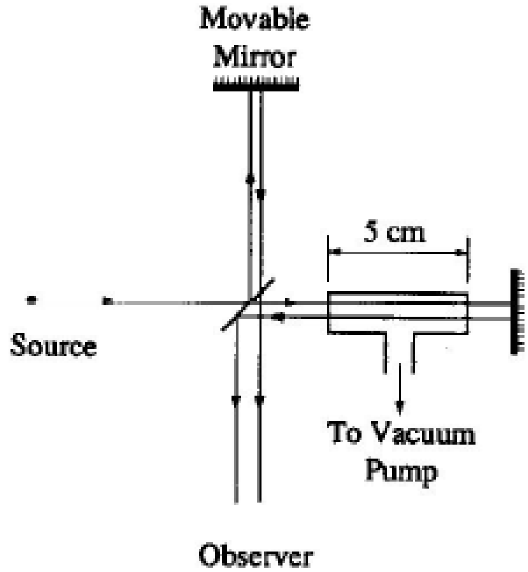
(B) 0.5 Å

(C) 2 Å

(D) 25 Å

(E) 50 Å

Problem 16:



A gas-filled cell of length 5 centimeters is inserted in one arm of a Michelson interferometer, as shown in the figure above. The interferometer is illuminated by light of wavelength 500 nanometers. As the gas is evacuated from the cell, 40 fringes cross a point in the field of view. The refractive index of this gas is most nearly

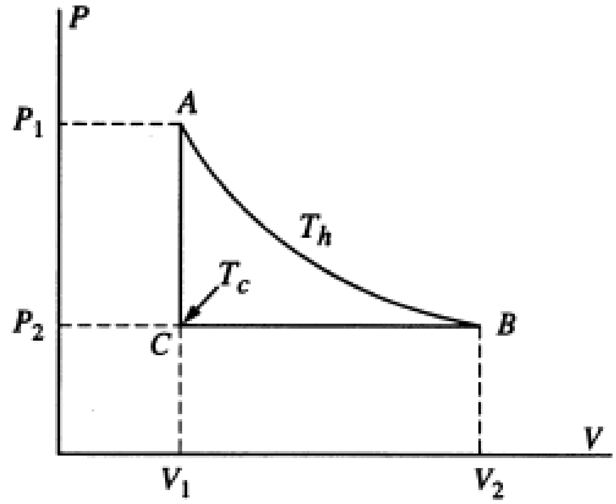
(A) 1.02
(B) 1.002
(C) 1.0002
(D) 1.00002
(E) 0.98

Problem 17:

The mean free path for the molecules of a gas is approximately given by $\frac{1}{\eta\sigma}$, where η is the number density and σ is the collision cross section. The mean free path for air molecules at room conditions is approximately

(A) 10^{-4} m
(B) 10^{-7} m
(C) 10^{-10} m
(D) 10^{-13} m
(E) 10^{-16} m

Problem 18:



Suppose one mole of an ideal gas undergoes the reversible cycle *ABCA* shown in the *P-V* diagram above, where *AB* is an isotherm. The molar heat capacities are C_p at constant pressure and C_v at constant volume. The net heat added to the gas during the cycle is equal to

(A) $RT_h V_2/V_1$

(B) $-C_p(T_h - T_c)$

(C) $C_v(T_h - T_c)$

(D) $RT_h \ln V_2/V_1 - C_p(T_h - T_c)$

(E) $RT_h \ln V_2/V_1 - R(T_h - T_c)$

Problem 19:

When alpha particles are directed onto atoms in a thin metal foil, some make very close collisions with the nuclei of the atoms and are scattered at large angles. If an alpha particle with an initial kinetic energy of 5 MeV happens to be scattered through an angle of 180°, which of the following must have been its distance of closest approach to the scattering nucleus? (Assume that the metal foil is made of silver, with $Z = 50$.)

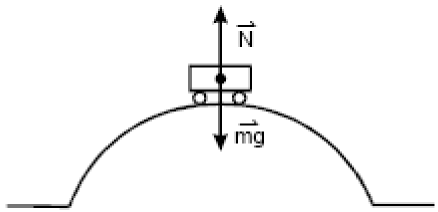
(A) $1.22 \times 50^{1/3}$ fm
(B) 2.9×10^{-14} m
(C) 1.0×10^{-12} m
(D) 3.0×10^{-8} m
(E) 1.7×10^{-7} m

Problem 20:

A helium atom, mass 4u, travels with nonrelativistic speed v normal to the surface of a certain material, makes an elastic collision with an (essentially free) surface atom, and leaves in the opposite direction with speed $0.6v$. The atom on the surface must be an atom of

(A) hydrogen, mass 1u
(B) helium, mass 4u
(C) carbon, mass 12u
(D) oxygen, mass 16u
(E) silicon, mass 28u

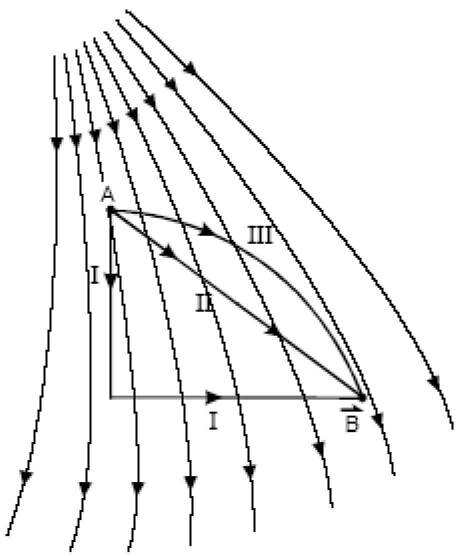
Problem 21:



The diagram shows the forces on a 600 kg car as it moves at 10 m/s over the top of a circular bridge with a radius of 50 meters. What is the magnitude of the normal force on the car at the top of the bridge?

(A) 1200 N
(B) 4680 N
(C) 5880 N
(D) 7080 N
(E) 9320 N

Problem 22:



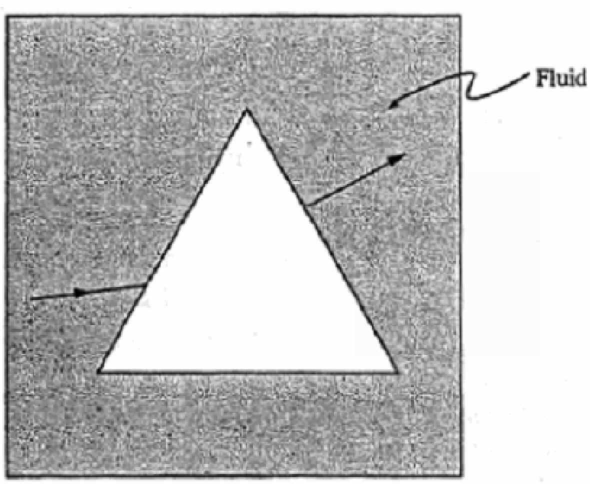
The diagram shows the lines of force for an static electric field, and three different paths linking points *A* and *B*. The work required to move a positive charge from point *A* to point *B* is evaluated over the three different paths. Which of the following statements about the work required to move the charge from *A* to *B* is true?

(A) The absolute value of the work will be the same for all of the paths.
(B) The absolute value of the work will be equal to zero for path I.
(C) The absolute value of the work will be greater for path II than for path III.
(D) The absolute value of the work will be greater for path III than for path II.
(E) The absolute value of the work will be greatest for path I.

Problem 23:
An object is placed 8 cm in front of a thin lens that has a focal length of 6 cm. At what distance from the lens will the image of the object be located?
(A) 2 cm
(B) 3.4 cm
(C) 7 cm
(D) 24 cm
(E) 8 cm

Problem 24:
If the temperature of the earth were to increase enough to melt the polar ice caps, a portion of the earth's mass would be redistributed away from its axis of rotation. Which of the following statements correctly describes a result of this mass redistribution?
(A) The angular momentum of the earth would increase, causing the earth to rotate faster.
(B) The moment of inertia of the earth would decrease, causing the earth to rotate faster.
(C) The angular momentum of the earth would decrease, causing the earth to rotate more slowly.
(D) The moment of inertia of the earth would increase, causing the earth to rotate more slowly.
(E) The rotation rate of the earth would not change, since a system cannot excert a net torque on itself.

Problem 25:



A glass prism bends a ray of light upward, as shown in the figure above. The index of refraction of the fluid surrounding the prism is
(A) zero
(B) less than the index of refraction of the glass prism
(C) equal to the index of refraction of the glass prism
(D) greater than the index of refraction of the glass prism
(E) negative