Decoherence: Objective round

"Equipped with his five senses, man explores the universe around him and calls the adventure Science"
- Edwin Hubble

Question Set 1:

Q.1A. A solid cylinder of uniform density is lying on a perfectly smooth floor and is acted upon by an impulse on its rim, as shown in figure 1. Which of the following is false? (in the Earth frame)

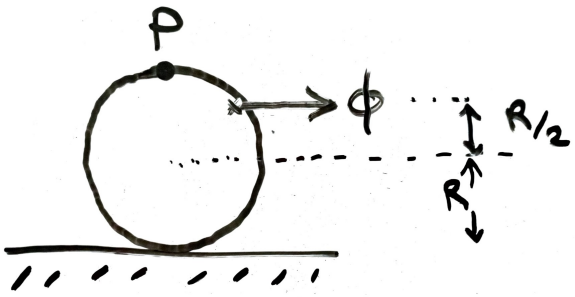

Figure 1: Cylinder on smooth floor

a. The torsional impulse due to ϕ about point P is out of the plane.
b. Immediately after the impulse, point P is moving forward.
c. When point P touches the floor, it has a forward velocity.
d. Immediately after the impulse, point P has a downward acceleration.

Q.1B. An L-shaped massless rod has masses 1 kg attached to each end. See figure 2. The rod is pivoted at point P. What is the time period of oscillations in the L-plane?

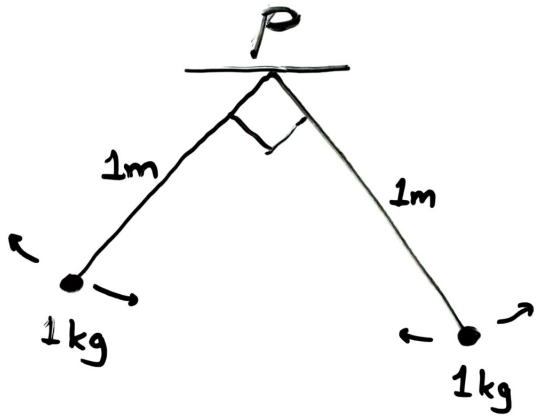

Figure 2: L-shaped rod

a. 2.4 s
b. 2.0 s
c. 1.7 s
d. 2.8 s

Q.1C. A torch emits light uniformly in a cone of some half angle θ. When the torch is held directly facing a uniform perfectly rough flat wall and switched on, the illuminated region forms a circle. The illumination at the edges is half the illumination at the centre. Find θ.
a. 45°
b. 30°
c. 60°
d. 75.5°

Question Set 2: Figure 3 shows an electric field line emerging from one charge q_1 in the electrostatic scenario shown, with no charges other than q_1 and q_2 present. $\alpha = \beta = 30^\circ$.

Q.2A. What is q_1/q_2?
a. 1
b. $\dfrac{1}{2-\sqrt{3}}$

c. $\frac{1}{\sqrt{3}} - \frac{1}{2}$
d. $\frac{2}{\sqrt{3}} - 1$

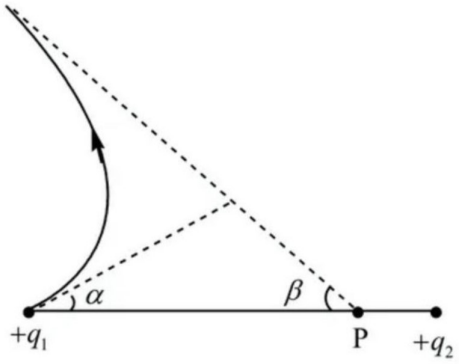

Figure 3: Electric field line

Q.2B. What would be the ratio of the distances of point P from charges q_1 and q_2 respectively?
(Hint: *Use multipole expansion*)
a. $4 + 2\sqrt{3} : 1$
b. $6 + 4\sqrt{3} : 1$
c. $3 + 3\sqrt{3} : 1$
d. $7 + 2\sqrt{3} : 2$

Q.2C. Now, consider a set of field lines neighbouring the one shown. During emergence from charge q_1, they subtend a solid angle Ω (very small). What is the solid angle subtended by these field lines far from the charges?
a. $\frac{6 + 4\sqrt{3}}{7 + 4\sqrt{3}}\Omega$
b. $(2 - \sqrt{3})\Omega$
c. $\frac{7 - 2\sqrt{3}}{2}\Omega$
d. $\frac{2 - \sqrt{3}}{2 + \sqrt{3}}\Omega$

Question Set 3: A lot of thermodynamic results are much more general than appreciated. Recall the formula for blackbody radiation. There is no mention of the actual radiation mechanism in the result. That's the beauty.

Q.3A. What is the energy density of thermal sound in the audible range at the centre of the Sun? (Assume the centre of the Sun to entirely contain ionized hydrogen behaving ideally at temperature $1.5 \times 10^7 K$.)(Audible range means frequencies between 20 Hz and 20 kHz.)
a. $3.0 \times 10^{-19} J/m^3$
b. $1.5 \times 10^{-19} J/m^3$
c. $5.0 \times 10^{-20} J/m^3$
d. $2.5 \times 10^{-20} J/m^3$

Q.3B. Two identical metal blocks at temperatures 200 K and 300 K are taken. The resistivity of the metal does not depend on temperature. These metal blocks are connected in series with an ideal electric power source. The power source is itself continuously charged by an ideal Carnot engine run between the two blocks. If the system is completely isolated, find the final/equilibrium temperature of the two blocks.
a. 240 K
b. 245 K
c. 250 K
d. 255 K

Q.3C. You are inside an optically dense object, and can not see anything outside. You are in a protective suit, but are fast running out of oxygen. You see that around you, some reactions are happening, leading to a heat production rate per unit volume of $100 W/m^3$. Since you are a physicist, you quickly assume that the object is spherical, and the energy production rate is uniform throughout. You measure the temperature to be $1000 K$. What is you estimate of the radius of the body?
a. 500 m
b. 900 m
c. 1.3 km
d. 1.7 km

Question Set 4: For every symmetry of nature, there exists a conserved quantity...

A particle of mass m is moving under the influence of a central potential $V(r)$.

Its initial position is $a\hat{e_x}$ and its initial velocity is $-u\hat{e_x} + u\hat{e_y}$. It is seen to follow a trajectory given by $r = ae^{-\theta}$ in polar co-ordinates. Work in the $v \ll c$ limit.

Q.4A. What is the time taken by the particle to cross the y-axis?
a. $0.79a/u$
b. $0.68a/u$
c. $0.48a/u$
d. $0.40a/u$

Q.4B. Which of the following can be a correct central potential for this scenario? (k being a specific dimensionful constant)
a. $-\frac{k}{r}$
b. $-\frac{k}{r^2}$
c. $-\frac{k}{r}e^{-\frac{r}{a}}$
d. $-\frac{k}{r^2}e^{-\frac{r}{a}}$

Q.4C. When the particle crosses the y-axis for the first time, it encounters another identical particle which is at rest. The collision is perfectly inelastic, and an electron-positron pair is produced. What can be said about m? (m_e is the mass of an electron.)
a. $m > 1.66\frac{m_e c^2}{u^2}$
b. $m > 0.35\frac{m_e c^2}{u^2}$
c. $m < 0.35\frac{m_e c^2}{u^2}$
d. $m < 1.66\frac{m_e c^2}{u^2}$

Question Set 5: And the 20th century began...

Q.5A. Consider figure 4. S is a regular conducting cylinder of diameter 1 m at room temperature, but becomes superconducting in liquid nitrogen. All resistors have a resistance of 1Ω, independent of temperature. This setup is placed in a region of uniform upward magnetic field of 1 Tesla. When liquid nitrogen is poured on S,

how much charge flows through the system?

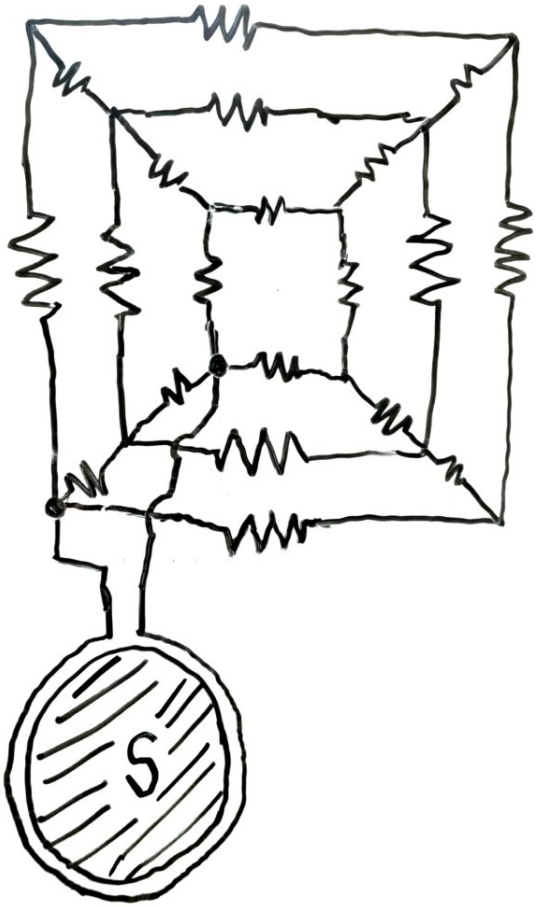

Figure 4: Superconductor and circuit

a. 0.98 C
b. 0.84 C
c. 0.71 C
d. 0.64 C

Q.5B. Which of the following is closest to the mean thermal energy of an electron above the ground state in a hydrogen atom at temperature $T = 300K$?
a. $8 \times 10^{-171} eV$

b. $3 \times 10^{-170} eV$
c. $8 \times 10^{-2} eV$
d. $3 \times 10^{-2} eV$

Q.5C. A beam of metal balls with density $\rho = 10\ balls/m^3$ with the balls travelling at half the speed of light exists in space. At rest, the balls are spherical with a diameter of 1 cm. A photon is travelling perpendicular to the beam. (See figure 5.) What is the probability that the photon is scattered?

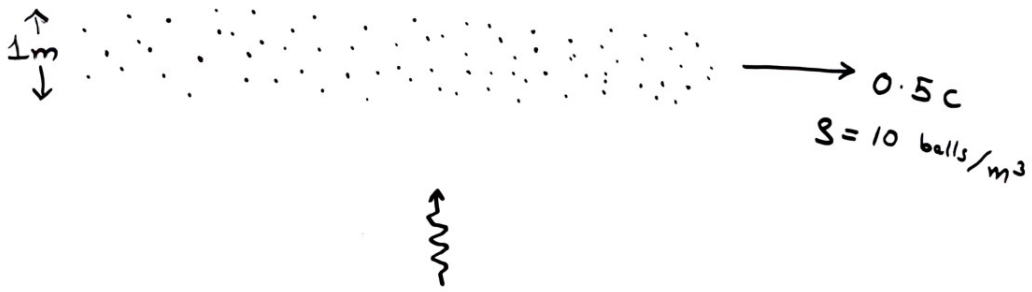

Figure 5: Photon across beam

a. 6.8×10^{-4}
b. 7.9×10^{-4}
c. 9.1×10^{-4}
d. 10.5×10^{-4}