2025 Online Physics Olympiad: Open Contest Problems

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Instructions

If you wish to request a clarification, please use this form. To see all clarifications, see this document.

- Use $g = 9.8$ m/s^2 in this contest, **unless otherwise specified**. See the constants sheet on the following page for other constants.
- This test contains 35 short answer questions. Each problem will have three possible attempts, unless otherwise specified.
- The weight of each question depends on our scoring system found here. Questions solved by fewer teams are worth more points, and the amount of points you get from a question decreases with the number of attempts that you take to solve it.
- Any team member is able to submit an attempt. Choosing to split up the work or doing each problem together is up to you. Note that after you have submitted an attempt, your teammates must refresh their page before they are able to see it.
- Answers should be within 1% relative accuracy unless otherwise specified.
- When submitting a response using scientific notation, please use exponential form. In other words, if your answer to a problem is $A \times 10^B$, please type AeB into the submission portal.
- A standard scientific or graphing handheld calculator *may* be used, along with technology and computer algebra systems like Wolfram Alpha or simple simulations. You are *allowed* to use Wikipedia or books in this exam.
- Asking for help on online forums or your teachers will be considered cheating and may result in a possible ban from future competitions. **The use of AI models such as ChatGPT is strictly forbidden.**
- Top scorers from this contest will qualify to compete in the Online Physics Olympiad *Invitational Contest*, which is an olympiad-style exam. More information will be provided to invitational qualifiers after the end of the *Open Contest*.
- In general, answer in SI units (meter, second, kilogram, watt, etc.) unless otherwise specified. Please input all angles in degrees unless otherwise specified.
- If the question asks to give your answer as a percent and your answer comes out to be "x%", please input the value x into the submission form.
- Do not put units in your answer on the submission portal! If your answer is "x meters", input only the value x into the submission portal.
- **Do not communicate information to anyone else except your team members before 12:00 AM UTC on August 10**.

List of Constants

- Proton mass, $m_p = 1.67 \cdot 10^{-27}$ kg
- Neutron mass, $m_n = 1.67 \cdot 10^{-27}$ kg
- Electron mass, $m_e = 9.11 \cdot 10^{-31}$ kg
- Avogadro's constant, $N_0 = 6.02 \cdot 10^{23}\ \mathrm{mol}^{-1}$
- Universal gas constant, $R = 8.31$ J/(mol · K)
- Boltzmann's constant, $k_B = 1.38 \cdot 10^{-23}$ J/K
- Electron charge magnitude, $e = 1.60 \cdot 10^{-19}$ C
- 1 electron volt, 1 eV $= 1.60 \cdot 10^{-19}$ J
- Speed of light, $c = 3.00 \cdot 10^8$ m/s
- Universal Gravitational constant,
$$G = 6.67 \cdot 10^{-11}\ (\mathrm{N \cdot m^2})/\mathrm{kg}^2$$
- Solar Mass
$$M_\odot = 1.988 \cdot 10^{30}\ \mathrm{kg}$$
- Acceleration due to gravity, $g = 9.8\ \mathrm{m/s^2}$
- 1 unified atomic mass unit,
$$1\ \mathrm{u} = 1.66 \cdot 10^{-27}\ \mathrm{kg} = 931\ \mathrm{MeV/c^2}$$
- Planck's constant,
$$h = 6.63 \cdot 10^{-34}\ \mathrm{J \cdot s} = 4.41 \cdot 10^{-15}\ \mathrm{eV \cdot s}$$
- Permittivity of free space,
$$\epsilon_0 = 8.85 \cdot 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$$
- Coulomb's law constant,
$$k = \frac{1}{4\pi\epsilon_0} = 8.99 \cdot 10^9\ (\mathrm{N \cdot m^2})/\mathrm{C^2}$$
- Permeability of free space,
$$\mu_0 = 4\pi \cdot 10^{-7}\ \mathrm{T \cdot m/A}$$
- Magnetic constant,
$$\frac{\mu_0}{4\pi} = 1 \cdot 10^{-7}\ (\mathrm{T \cdot m})/\mathrm{A}$$
- 1 atmospheric pressure,
$$1\ \mathrm{atm} = 1.01 \cdot 10^5\ \mathrm{N/m^2} = 1.01 \cdot 10^5\ \mathrm{Pa}$$
- Wien's displacement constant, $b = 2.9 \cdot 10^{-3}$ m · K
- Stefan-Boltzmann constant,
$$\sigma = 5.67 \cdot 10^{-8}\ \mathrm{W/m^2/K^4}$$

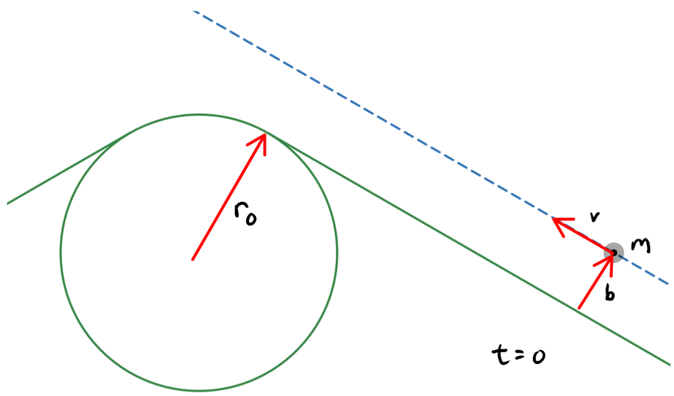
Problems

1. Free Bird

The rest mass of the observable universe is 1.5×10^{53} kg as measured in the Earth frame. If βc is the maximum possible speed of an electron in this frame, find $1 - \beta$. Ignore the effects of general relativity.

2. Racing Line

A race track is constructed from two semi-infinite straight sections, joined by a circular turn of radius $r_0 = 1$ m and angle $\theta = 120°$. A small race car of mass m moves along the straight section of the track at a constant speed v_0 and impact parameter $b = 0.5$ m from the inner wall of the track. At time $t = 0$ s, the driver rotates the steering wheel by a fixed amount, setting the car into uniform circular motion as it goes around the turn. At a later time $t = t_{min}$, the driver exits the turn by straightening the steering wheel and begins to move in a straight line staying distance b from the inner wall of the race track. Given $\mu_s = 1$ and assuming that the car does not skid or change its speed along its path, find the maximum speed possible for the car to complete the turn.



3. The Cake is a Lie

Two identical rectangular portals are set horizontally in a watertight chamber such that no water can escape. A solid cylindrical water wheel with mass $m = 10$ kg and radius R is mounted such that its horizontal axle is halfway between the two portals. Each paddle of the wheel extends a small distance $r \ll R$ and the wheel is positioned so that when a paddle is horizontal it fits entirely between the portals and exactly lines up with the portal openings. Water entering a portal is instantaneously transported to the corresponding location on the other portal and emerges with the same velocity it had upon entry. The portals do not interact with the water wheel. At time $t = 0$, a horizontal slab of water with mass m, initially at rest, is released from directly under the top portal. Determine the energy of the wheel after 5929 minutes.

4. Fiber Optics

A laser emitting light of wavelength $\lambda = 1$ μm is coupled with a straight optical fibre of refractive index $n = 1.5$, radius $r = 0.1$ mm and length $l = 100$ m. The laser periodically transmits impulses of very narrow width. Find the maximum frequency of pulse transmission that can guarantee that the receiver on the other end of the fibre can distinguish between pulses without interference.

5. Cosmological GPS

In a future where humanity is travelling outside of our galaxy, GPS satellites are scattered throughout Local Group and beyond to provide for the navigational needs of intergalactic travellers. A traveller in the Andromeda galaxy, 2.5 million light years away, connects to a satellite in the Milky Way. Calculate the error in position reported by the satellite caused by the expansion of the universe. The Hubble constant is $2.27 \times 10^{-18}\ \mathrm{s}^{-1}$, and it gives a cosmological velocity $v = H_0 d$ away from the observer.

6. Water Droplet

Find the maximum height of a water droplet on a flat table. The density of water is $\rho = 1000\ \mathrm{kg/m}^3$ and the surface tension between water and air is $\gamma = 7.28 \cdot 10^{-2}\ \mathrm{N/m}$. Assume that the surface tensions between the table and air or water are 0.

7. A Balancing Act

A pencil of uniform density and length $\ell = 10$ cm is vertically oriented and a frictionless pivot is put a distance d below the midpoint of the pencil. The pencil is then let go. Find the maximum d such that the pencil will remain stably upright. Neglect all forces except gravitational forces and the normal force from the pivot. Treat the Earth as spherically symmetric with radius 6378 km.

The following applies for the next two problems. It is possible to do a cool trick using a plastic water bottle. In the following two problems, we will analyze the conditions required for such a trick to be performed. The procedure is as follows:

- Empty a small plastic water bottle, and dry it such that it has no liquid water inside. The interior air will have the same temperature and composition as the room's air.
- Screw the cap tightly onto the bottle such that it is airtight.
- Twist the bottle, such that the air in the bottle is effectively compressed to 95% of its original volume. The twisting process is done quickly enough that negligible heat is transferred to/from the interior air.
- After waiting for a while, the interior air returns to room temperature. Unscrew the bottle cap, causing it to pop out quickly. A fine mist is produced.

You may treat the air, and all of its components, as an ideal diatomic gas. The room temperature is $T_0 = 20.0°\mathrm{C}$. If you need the vapour pressure of water, use the Buck formula at this online calculator.

8. Bottle trick 1

Find the minimum relative humidity the room's air needs to have for this trick to work. Give your answer as a decimal (where 1 would mean that the air is saturated with water vapour).

9. Bottle trick 2

Immediately after twisting the bottle, water droplets form on the inside wall of the water bottle. Find the minimum relative humidity of the air that allows for the water droplets to form.

10. Frosty

Four ice cubes are placed in different environments.All the ice cubes are the same size. Your goal is to determine which of ice cube 1 or 2 fully turns to liquid first, and which of ice cube 3 or 4 fully turns to vapor first.

1. Ice cube 1 is at room temperature in a slightly **more** humid atmosphere.
2. Ice cube 2 is at room temperature in a slightly **less** humid atmosphere.
3. Ice cube 3 is on a hot plate at 100°C in a slightly **more** humid atmosphere.
4. Ice cube 4 is on a hot plate at 100°C in a slightly **less** humid atmosphere.

You may neglect heat conduction and heat capacity of air, and assume that the difference in humidity does not significantly change the boiling point. The room is much larger than the ice cube and the ice cubes are of similar size to the hot plate.

Submit the solution as a 2 digit number as follows:

- The tens digit is 1 if ice cube 1 melts first, 2 if ice cube 2 melts first and 9 if they take the same time.
- The ones digit is 3 if ice cube 3 boils first, 4 if ice cube 4 boils first and 9 if they take the same time.

For example, if ice cube 2 melts first and ice cube 4 boils first, submit the answer 24. **Only one attempt will be accepted for this problem.**

11. Electric Disco

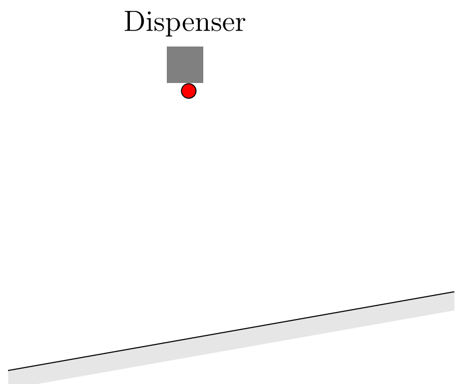
A thin, conductive disk of radius 1 m is centred at the origin of the xy-plane, with axis perpendicular to the plane. The potential at the boundary is given by $V(x, y) = x(xy + 1) + y(y + 1)$ V, where x and y are in meters. What angle, in radians, does the current density at the origin make with respect to the x-axis?

12. Bungee Jumping

Consider a thin hoop of radius 1 m, upon which lies four frictionless beads of mass 0.1 kg forming two pairs of beads connected by centrally pivoting diametric rods, not unlike a pair of scissors. Consider four elastic "bungee" cords, created by cutting up a single elastic cord of relaxed length 5 m and spring constant 10 N/m. These four elastic cords, connected bead to bead, are relaxed but not slack at equilibrium. Find the period of small oscillations about this equilibrium point.

13. Bouncing Down the Slope

A dispenser releases small identical uniform disks of mass $m = 2$ kg from rest at a height $h = 50$ m above a long frictionless wedge of mass $M = 500$ kg at a uniform rate of 50 disks per second, beginning at $t = 0$. The wedge is angled at $\theta = 10^\circ$ above the horizontal and is fixed on top of a horizontal scale. The disks collide with the slope with a coefficient of restitution $\alpha = 0.95$. Find the reading on the scale after time $t = 150\,\mathrm{s}$ in Newtons, averaged over the timescale of a few ball collisions (the scale measures the vertical force exerted on it). Assume that the incline is sufficiently long such that no disks leave the incline.



14. Gravity Cable Car

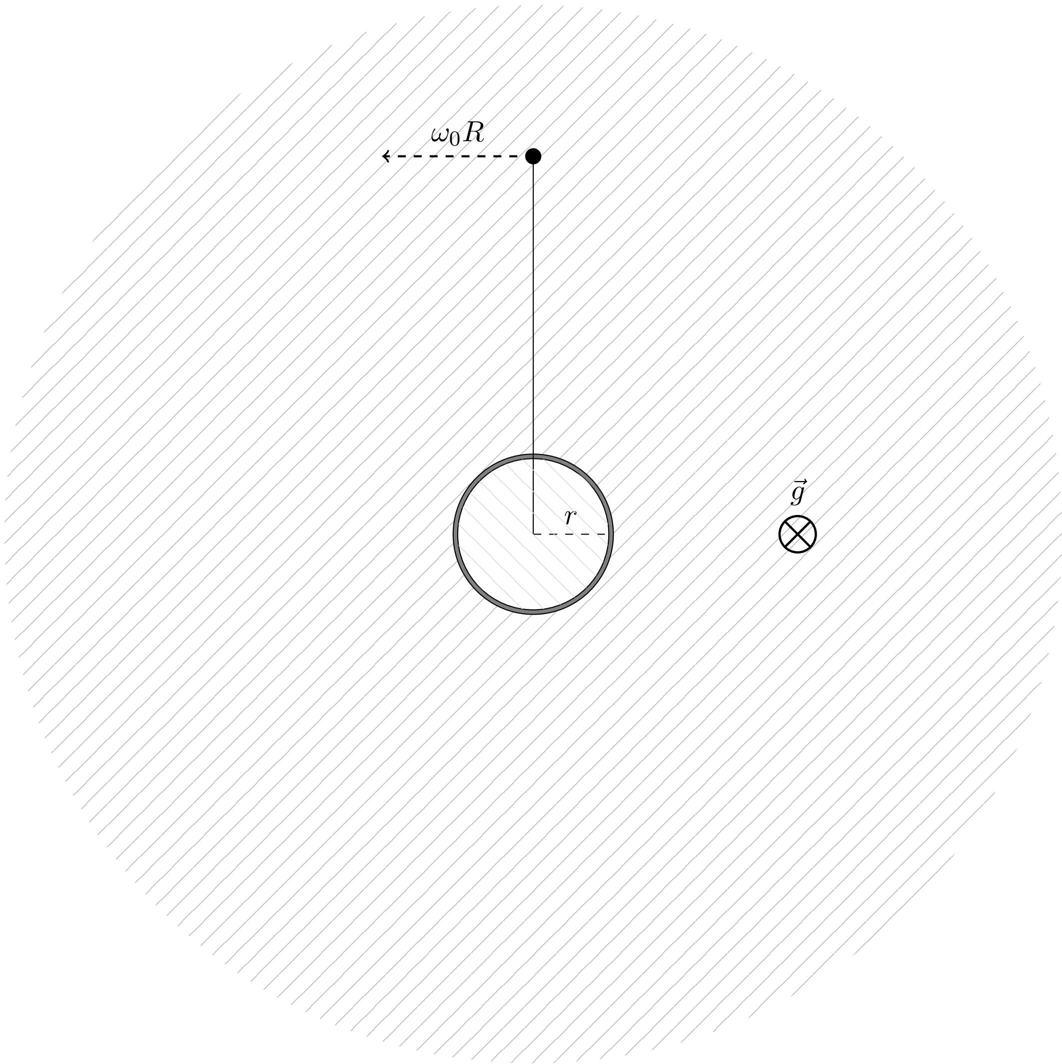
An inextensible cable of length l is hung over a valley of width $l_0 = l/2$. The two walls of the valley are at the same altitude. A cable car is fastened to rollers at one end of the rope, gently lowered along the wall of the valley until it cannot go any further down, and let go. If the cable car takes time T to cross the valley, find $T\sqrt{g/\ell_0}$. You may assume the mass of the cable car is much larger than the mass of the cable itself, and neglect friction.

15. Magnetic Monopole

Consider a hypothetical magnetic monopole of magnetic charge $q_\mathrm{m} = 10^{-5}$ T·m^2 and mass $m = 10^{-10}$ kg placed at the center of a fixed ring of resistance $R = 5\ \Omega$ and radius $r = 2$ m. The monopole is given an initial velocity along the axis of the ring. Find the minimum velocity v_m such that the monopole can escape from the ring. Assume that the magnetic field produced due to a magnetic monopole is $\vec{B} = \frac{q_\mathrm{m}}{r^2}\hat{r}$ and that the magnetic force acting on a magnetic monopole is $\vec{F} = \frac{q_\mathrm{m}}{\mu_0}\vec{B}$.

16. Variant Roulette, House Edge

A spinner, modeled by a massless rod of length R connected to a point mass, is attached to the center of a massless cylinder (pin) of radius r. The cylinder is almost perfectly fit in a hole in a floor, that is, the cylinder is slightly smaller than the hole. The spinner, laid perfectly flat on the floor and starting at $\theta = 0$, is given a random angular velocity in the interval $(0, \omega_L)$, where ω_L produces exactly $N \gg 1$ full rotations (assume classical mechanics). What is the probability that it lands in the region $\pi/2 < \theta < 3\pi/2$ if there is a coefficient of friction $\mu = 50$ between the pin and the hole and $r/R = 0.2$?



17. Squid Game

We model a prehensile octopus tentacle of length $L = 2$ m as made of very many servomotors, each of which can apply a torque $\tau = 4$ N·m about any axis. An octopus wishes to pick up a cylinder of radius $r = 4$ cm and mass m by wrapping the tentacle around the side and lifting it such that its axis points straight up. What is the maximum M the octopus can pick up? Coefficient of friction between tentacle and cylinder is $\mu = 0.001$. Neglect buoyancy. Respond with 42.0 if the answer is infinite.

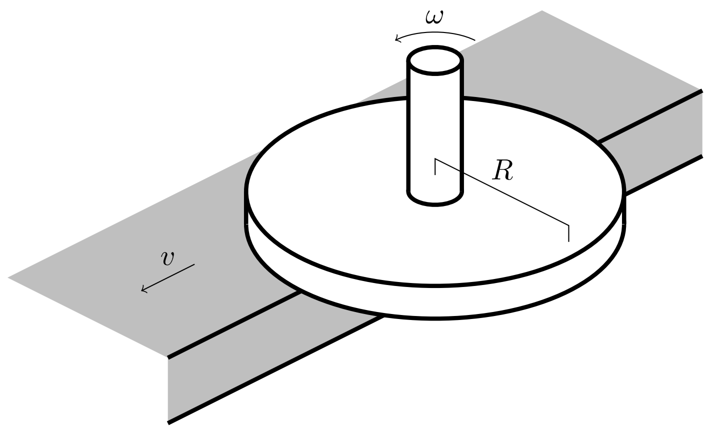
Hint: μ is very small, so the octopus is able to lift the cylinder if and only if it can get a grip on it.

18. Radioactive

A thin disk made up of one millimole of $^{210}_{84}$Po lies face down on a frictionless table. Find the expected speed of the disk after one half life. $^{210}_{84}$Po has mass $M_0 = 195.5978$ GeV/c^2 and decays to $^{206}_{82}$Pb with mass $M_1 = 191.8547$ GeV/c^2, emitting an alpha particle with mass $m_\alpha = 3.7274$ GeV/c^2.

19. Arctic Circle

A freely rotating disk of radius R, made of ice at its melting point, is pressed against a belt moving at speed v such that the disk's center is at the edge of the belt. Due to drag, the disk rotates at constant angular velocity. The drag force per unit area is linear (proportional to relative velocity). Find the ratio between the largest and smallest time-averaged rates of melting at a point on the disk. Assume that the pressure is constant across the disk.



20. Hexagons are the Bestagons

Consider a two dimensional universe. In the centre of a hexagonal chamber with side length 1 m lies a 10 W light source. The interior of the chamber is perfectly reflective. What is the pressure at the centre of one of the walls 12 ns after the light is turned on? Note that pressure in this case indicates force per length.

21. Spring-loaded capacitor

A capacitor is made of two flat metal plates, each of area $A = 20\ \text{mm}^2$, separated by a spring of spring constant $k = 150$ N/m and natural length $d_0 = 0.01$ mm. The plates of the capacitor is then connected to a function generator which outputs a voltage $V(t)$, which consists of a DC component V_0. It is found that for some values of V_0 and some initial distances between the plate, the plate settles into an oscillation about a certain point. V_0 is increased until just below the point where this behaviour no longer applies, and then adjusted to half of this maximum value. The capacitor is then pulled apart to a distance y and released; the two plates slam together. Find the minimum y.

22. Supernucleus

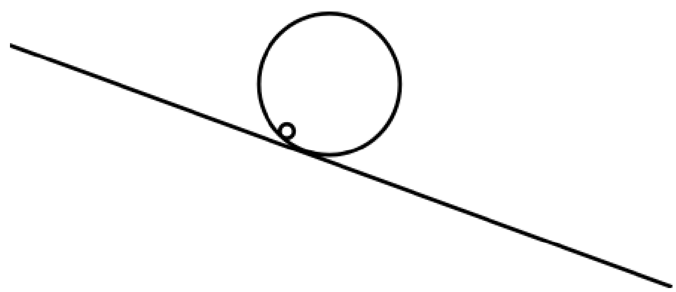
Scientists at CERN have recently been working on a novel super-nucleus - a nucleus with a mass number of $A = 16000$ and $Z = 1$ proton. Its radius is unusually small, at $R = 10^{-15}$ m. As is the natural decision to make, they've decided to place the super-nucleus in a box full of electron plasma at a temperature $kT = 100$ eV. Given the electron density of the plasma $n = 10^{19}\ \text{m}^{-3}$, what is the mean time between electron collision with the nucleus? Treat all particles classically.

23. I-Conic

A solid cone of uniform density, with slant height 2 m and base radius 1 m, lies on its curved face in stable equilibrium on a slanted plane such that its axis is horizontal. There is a very high coefficient of friction between the cone and the plane. Find the frequency of small oscillations about this equilibrium.

24. Spontaneous Rotation

A hollow superconducting sphere of radius R and mass M_1 and is placed on an inclined plane with angle α with respect to the horizontal. Inside that sphere lies another hollow sphere with radius a and mass $M_2 \ll M_1$ which has a total charge Q. After some time, The sphere manages to spontaneously start rotating along the axis going through its center and the point where it touches the bigger sphere. Find the smallest value of the induced magnetic moment m that would make the smaller sphere lift off instantaneously. All surfaces are frictionless. Take $R = 10$ cm, $a = 3$ cm, $\alpha = 30$, and $M_2 = 100$ g.



25. Relativistic Race

A relativistic tortoise and rabbit are racing. Both animals start running from rest at $t = 0$ in the lab frame along a one-dimensional racetrack. To see who wins the race, Biologist Billy gives each animal a stopwatch initially set to 0, which they start at $t = 0$ and stop when they cross the finish line. Unfortunately, when the animals return the stopwatches to Billy, he finds that they both read the same value! The tortoise's proper acceleration is $a_t = 1.10 \cdot 10^6$ m/s^2, and the rabbit's proper acceleration is $\frac{c}{t_r + k_2}$, where t_r is the rabbit's proper stopwatch reading and $k_2 = 190$ s. In the lab frame, who won the race, and by how much time?

Input the positive value in seconds for the margin of victory if the tortoise won and the negative value if the rabbit won. You may find an online integral calculator such as Wolfram Alpha or this one to be helpful.

26. Glass Block

Steve holds a long square prism with refractive index 3/2 in midair such that its axis is horizontal. Sunlight is shining on the block. If the magnitude of the radiative force exerted on the block is at half of its maximum possible value, find the smallest angle of a block face to the plane formed by the line from the Sun to the centre of the prism and the horizontal. Assume that no light is reflected when entering the block.

27. Sproing

Two point masses of mass $M = 59$ kg are attached to opposite ends of a spring with nonzero rest length. The spring has mass $m = 2$ kg and spring constant $k = 9$ N/m. The system is placed in a frictionless and massless tube which rotates around the center of mass of the system with a **fixed** angular velocity. In the ensuing oscillation, suppose the orbital path of each of the masses is periodic without intersecting with itself. Find the maximum angular velocity for which this is possible.

28. Five Big Booms

A spherically symmetric explosion occurs at a point along the axis of a very long cylindrical chamber with radius R. A sensor is a distance R along the axis from the explosion and can be modeled as a sphere of radius $r \ll R$. Given that $r/R = 10^{-30}$, find the proportion of energy eventually absorbed by the sensor to within 1% relative accuracy. The walls of the chamber are perfectly reflecting.

29. Hang in there!

Consider a very long cylindrical neodymium magnet with radius $R = 0.450$ m, uniform longitudinal magnetisation $M = 5.00 \times 10^5$ A/m, and density $\rho = 7500$ kg/m^3. The magnet is held vertically by its top end. To within 1% relative accuracy, find the distance L from the bottom of the magnet where there is no tensile stress in the material (averaged over the cross-section).

30. Fly Away

In the lab frame, two birds fly counterclockwise with speed u around a circle with radius R, starting an angle $\pi/2$ apart. An observer moves at speed v relative to the lab frame. In the observer's frame, the maximum distance between the birds is s. Over all values $u, v < c$, find the maximum of s/R.

31. Unconventional Oscillations

A thin uniform wire with mass per unit length $\lambda = 5.0 \times 10^{-5}$ kg/m is shaped into a circular loop and carries a constant current $I = 10$ A. It is placed in a uniform electric field $\mathbf{E} = E\hat{\mathbf{z}}$, with its axis of rotational symmetry parallel to $\hat{\mathbf{x}}$. The wire loop is given an initial angular velocity $\boldsymbol{\omega_0} = \omega_0\hat{\mathbf{z}}$ about its center. Curiously, when $|\omega_0| < \omega_c$, the loop never makes a full rotation with respect to its center. Find ω_c in rad/s.

The magnitude of the electric field is $E = 1000$ V/m. Assume that the experiment is conducted in a vacuum, and there is no external gravitational or magnetic field.

32. Star Power

Fusion takes place when two protons are less than 1.5 fm apart. One gram of hydrogen gas at room temperature and pressure is adiabatically compressed by lasers in a fusion reactor into a volume of 10^{-10} m^3. Find the peak output power of the fusion reactor. You may assume that other than the proton-deuteron fusion reaction, $H + H \to D + \nu$, no further fusion reactions take place. **The accuracy of this problem should be within 5%**.

33. Party Popper

A balloon at surface tension $\sigma = 50$ N/m is filled up with diatomic ideal gas via a hand pump of volume 1 L in a room of temperature 300 K at atmospheric pressure $p_0 = 10^5$ Pa. Find the number of strokes required to pump the balloon to bursting, assuming that it bursts when its radius reaches 50 cm. Assume the gas in the hand pump has the same pressure as the gas in the balloon as the gas is pumped into the balloon. Give the exact answer ± 1. Neglect thermal conduction and radiation.

34. A Cloudy Day

After an asteroid impact the middle of a large ocean, a hypercane is forming. The surface temperature is measured to be 320 K and the pressure to be 10^5 Pa. By considering what happens to a parcel of air picking up moisture from the ocean surface as it rises adiabatically in the atmosphere, find to within 10% accuracy the highest altitude at which clouds can form. The latent heat of water is 2260 kJ/kg. You may assume that water vapour is an ideal gas with molar mass 18 g/mol and dry air is a diatomic ideal gas with molar mass 29 g/mol. Also assume that relative humidity may not exceed 100%.

35. Airplane, QED

In their quest for world domination, the OPhO committee has created an airplane beam generator (ABG) which produces a set of positively charged airplanes and negatively charged anti-airplanes. These airplanes have mass $m = m_e$, where m_e is the mass of an electron, and are produced at speed $v = 1.00 \cdot 10^{-3}c$. The two beams are offset by an angle of $135°$. The left facing, positive beam is positioned at $45°$ above the horizontal and hence the right facing, negative beam is parallel to the horizontal.

They mount the ABG on a rail which is mounted parallel to the vertical, and can hence move up and down freely. They set up a magnetic field such that in the 2nd quadrant and the top left half (from the horizontal to $45°$ down from the horizontal) of the 3rd quadrant, the field is $B\sqrt{2}$ out of the page, and in the 1st and 4th quadrant, the field is $B = 1$ T out of the page. The ABG is then moved such that the two beams intersect at the origin, and there is a phase difference of exactly 2π between the beams at the origin. What must be the charge q on the airplane for this to occur? Assume the airplane source is coherent and that there is no initial phase difference. Make sure to submit $|q|$.