Harvard Undergraduate Science Olympiad Dubai
2026 Final Round
9th-10th Grade
Physics Section: Exam

NAME: ______________________

Student ID: _________________

Score: ____/160

Important Constant Values

Name	**Symbol**	**Value**	**Units**
Gravitational Accel. On Earth	g	9.81	m/s^2
Universal Gravity Constant	G	6.674×10^{-11}	$\frac{m^3}{kg\, s^2}$
Speed of Light	c	2.998×10^{8}	$\frac{m}{s}$
Mass of Proton	m_p	1.673×10^{-27}	kg
Mass of Neutron	m_n	1.675×10^{-27}	kg
Mass of Electron	m_e	9.109×10^{-31}	kg
Universal Gas Constant	R	8.315	$\frac{J}{mol\, K}$
Permittivity of Free Space	ϵ_0	8.854×10^{-12}	$\frac{A^2 s^4}{m^3 kg}$
Permeability of Free Space	μ_0	$4\pi \times 10^{-7}$	$\frac{m\, kg}{A^2 s^2}$
Avogadro's Number	N_A	6.022×10^{23}	$\frac{1}{mol}$
Elementary Charge	e	1.602×10^{-19}	C
Speed of Sound in Dry Air (STP)	v_s	343	$\frac{m}{s}$

Important Formulas

$v_f = v_i + at$	$x_f = x_i + v_i t + \frac{at^2}{2}$	$v_f^{\ 2} = v_i^{\ 2} + 2a(x_f - x_i)$
$F = ma$	$a = \frac{v^2}{r}$	$p = mv$
$F_f = \mu N$	$F_k = - kx$	$W = Fd$
$KE = \frac{mv^2}{2}$	$U_g = mgh$	$U_k = \frac{kx^2}{2}$

$I_d = I_0 + md^2$	$L = I\omega$	$\tau = I\alpha$
$I_{ring} = mr^2$	$I_{disk} = \frac{mr^2}{2}$	$I_{stick,\, center} = \frac{ml^2}{12}$
$f = \frac{\omega}{2\pi} = \frac{1}{T}$	$T = 2\pi\sqrt{\frac{L}{g}}$	$T = 2\pi\sqrt{\frac{m}{k}}$
$F_E = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$	$F = qE$	$V =- Ed$
$F_G = \frac{Gm_1 m_2}{r^2}$	$R_{eq,\, series} = \Sigma R$	$\frac{1}{R_{eq,\, parallel}} = \Sigma\frac{1}{R}$
$V = IR$	$I = \frac{q}{t}$	$E = hf$
$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$	$f = \frac{r}{2}$	$v = \lambda f$

INSTRUCTIONS:

The HUSO Dubai Final Round Physics section consists of 10 problems. Each problem will contain several subsections, with point values provided in parentheses. Raise your hand if you think you found a mistake or if you have questions. Also, raise your hand if you are missing some of the 11 pages from this exam. You may spend 1 hrs on the Physics section and may not work on any other section during this time.

All answers must be written in the designated answer sheets. Any writing on the exam booklet outside the answer sheets will not be graded. You may write in this booklet, but **NO WRITING IN THIS BOOKLET WILL BE GRADED.** Feel free to use this booklet as extra scratch paper. Partial credit will not be given for an incorrect answer. However, incorrect answers will *not* lead to negative points.

The Physics section will contain several short answer questions. Each short answer question will have several subsections, each of which will only require a numerical answer, algebraic expression, or a few words. All algebraic answers can be written in terms of given variables and universal constants. If you make a mistake in an earlier part of a question and a later part of the question requires your earlier answer, full credit will be given if your calculations in the later part are correct but your answer is wrong because you use the wrong value from the last part.

You must bring a #2 pencil or pen, and an eraser. You are allowed to bring a non-programmable, non-graphing calculator and a wrist-watch. You are not allowed to bring a smart watch, textbooks, notes, or any other electronic devices.

Best of luck!

1. House of Mirrors

Throughout this whole problem, assume that you keep your head level (you only turn your head left or right, not up or down).

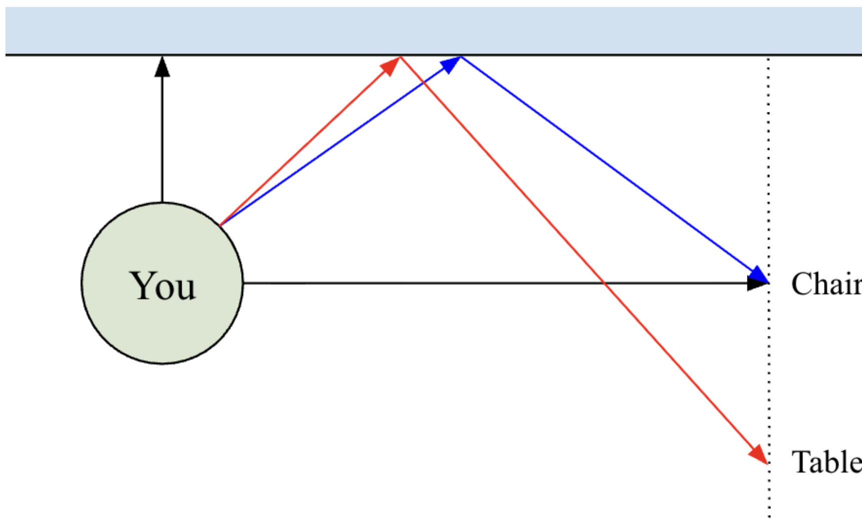

Fig. 1: Objects in a mirror

a. You walk into a room that features a large, flat mirror on one wall. You look immediately forward and see yourself in the mirror. You look to the right, and see that you are in line with a chair. You are 2 meters away from the mirror. If you look towards the mirror, 60˚ to the right, you can see the chair in the mirror. How far are you from the chair? (4)

b. You also notice a table that is aligned with the chair (if there was a line connecting the table and chair, it would be perpendicular to the mirror). If you need to look 45˚ to the right to see the table, how far is the table away from the mirror? (4)

c. How far is the table away from the chair? (3)

d. How far is the table away from you? (5)

2. The Great Block of Ice

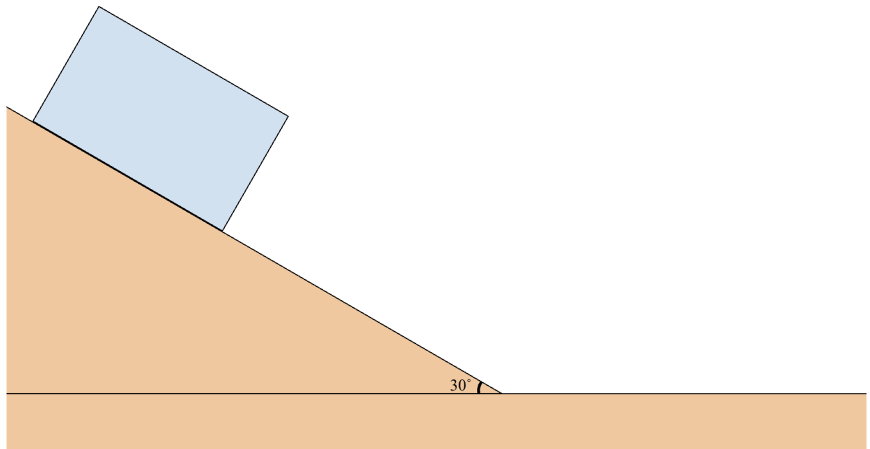

Fig. 2: A Block of Ice on a Hill

a. A very large block of ice is sliding down a hill angled at 30˚. Using the fact that the density of ice is about 900 kg/m^3, what is the mass of the block of ice in kg if it has a width of 15 meters, a length of 20 meters, and a height of 10 meters? (2)

b. Assuming that there is no friction between the ice and the hill, what is the acceleration of the ice? (3)

c. Now, the ice is travelling on flat ground with an initial speed of 83.3 m/s. If there is a coefficient of friction between the ice and flat ground of 0.25, what will the speed of the ice be after 12 seconds? (5)

d. How many seconds will it take in total for the block to come to a complete stop? (4)

3. Flight of the Bumblebee

a. A bumblebee is flying in a perfect circle with a radius of 2 meters, and a speed of 15 m/s. How many seconds will it take for the bee to complete one lap? (3)

b. In radians per second, what is the angular velocity of the bee? (3)

c. Assuming that the speed of the bee is constant, what is the bee's radial acceleration? (3)

d. Assuming that the speed of the bee is constant, what is the bee's tangential acceleration? (3)

e. If the mass of the bee is 1×10^{-4} kg, what is the force needed to ensure that the bee can fly at this speed? (5)

4. Look at this Graph

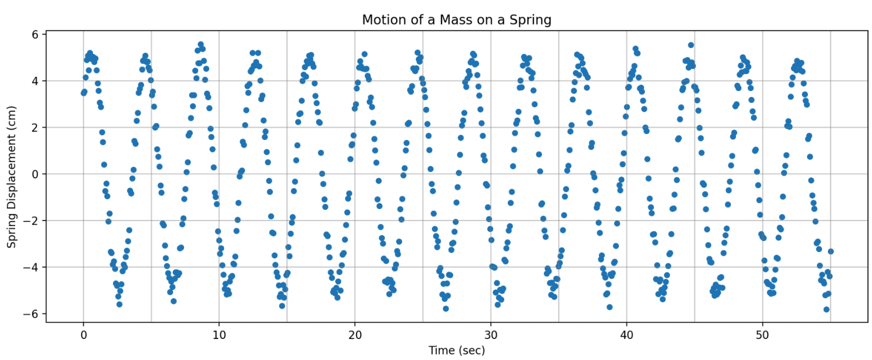

Fig. 3: Graph for part a.

a. Oscillation data is plotted in the above graph. Find the period and amplitude. (4)

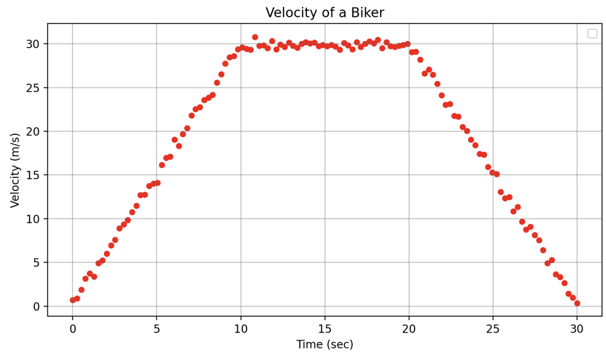

Fig. 4: Graph for parts b. and c. All motion is along x direction.

b. For each individual time frame, determine what the bike's acceleration is. (3 each)

i. $0 < t < 10$

ii. $0 < t < 10$

iii. $0 < t < 10$

c. What is the total displacement of the bike from the period of 0 to 30 seconds? (4)

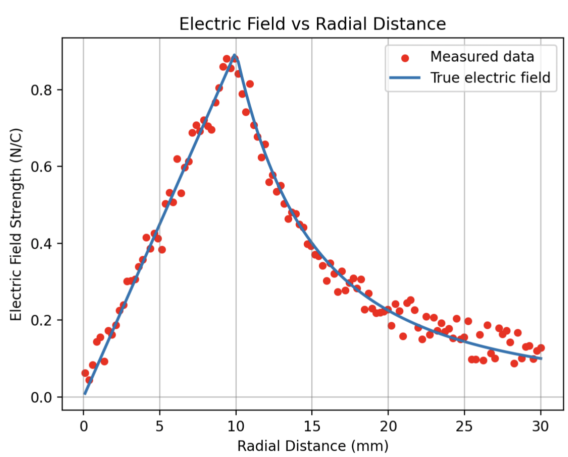

Fig. 5: Graph for parts d.

d. The above graph shows the electric field as a function of radial distance away from the center of a charge distribution. Qualitatively describe what the charge distribution looks like. (6)

5. Taking a Rocketship to Space

a. Assume that the mass of a planet is M and the mass of a rocket on the surface of the planet is m. If the planet as a radius of R, what is the expression for the gravitational potential energy between the planet and the rocket? (4)

b. Suppose instead of a typical rocket launch, all of the rocket's fuel gets expelled in one shot. Come up with an expression for the velocity that the rocket would need to be launched at to escape from the Earth's gravity. (5)

c. The Earth has a density of 5.5×10^3 kg/m^3, and a radius of 6.371×10^6 meters. What is the escape velocity on the surface of Earth? (3)

6. A House of Cards

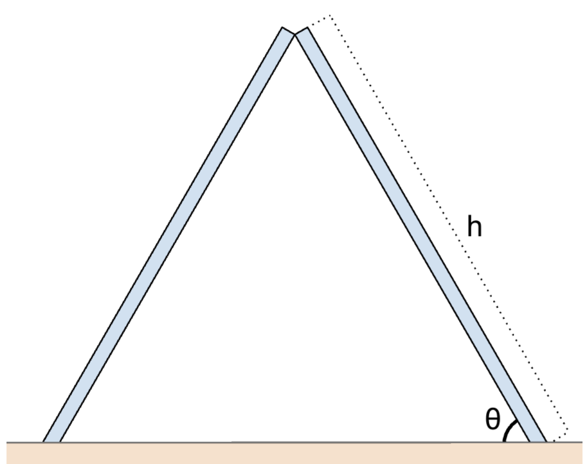

Fig. 6: A Simple Card Tower.

a. You are building a tower out of cards that consists of two cards leaning against each other. Taking the mass of each card to be m, the height of each card to be h, and the θ given in the figure, determine the magnitude of the contact force at the top of each card. (4)

b. What is the minimum coefficient of friction necessary between the card and the table to make sure that the card doesn't slip? (3)

c. Suppose you pressed downwards on the top of the cardtower with a force equal to $\frac{mg}{2}$, such that each card feels a downwards force of $\frac{mg}{4}$ applied at the top. What is the new minimum coefficient of friction? (4)

7. The Mighty Electron

a. An electron moving in the $+x$ direction enters a region with a uniform magnetic field pointed in the -z direction. What direction will the force on the electron point? (2)

b. If the initial speed of the electron is 1.5×10^7 m/s, and the magnitude of the magnetic field is 0.01 T, what is the radius of curvature for the path of the electron inside the region with the magnetic field? (4)

c. Now imagine that the electron is in the middle of the region of magnetic field. Suppose that we now want to flip the direction of the magnetic field after every complete lap. Draw or describe the path that the electron would take. (4)

d. In order to achieve the exact timing necessary for the magnetic field to flip after every direction, what will the frequency of the switching need to be in GHz? (4)

8. A Very Complex Circuit

a. What is the total resistance of a series circuit that contains three resistors, with each one having a resistance of 2 Ω? (2)

Impedance is a way of measuring the "resistance" of an AC circuit. Impedances for different circuit components add in the same way resistances do for resistors. In a circuit oscillating with an angular frequency of ω, we assign $X_L = \omega L$ and $X_C = (\omega C)^{-1}$. The impedance of a resistor is R, the impedance of an inductor is iX_L, and the impedance of a capacitor is $-\ iX_C$.

b. Find $R,\ X_L$, and X_C for a series circuit with a 2 Ω resistor, 2 F capacitor, and a 2 H inductor, and an angular frequency of $\omega\ =\ 5$ rad/sec. (3)

c. The impedance of a series RLC circuit is given by $\sqrt{R^2 + (X_L - X_C)^2}$. What is the impedance of the circuit described in part b? (3)

d. The resonant frequency is the angular frequency that minimizes the impedance of an RLC circuit. What is the resonant frequency of the given circuit? (4)

9. An Ideal Problem

a. You have 15 moles of gas contained inside a piston. The conditions in the piston start at 400 K and 1 MPa. If one cubic meter of volume is equivalent to 1000 liters, how many liters does the gas occupy? (3)

b. An isobaric process is a thermodynamic process that doesn't change the number of moles or the pressure, but changes the temperature and volume. Suppose the gas in the piston from part a undergoes an isobaric process that doubles the volume. What is the new temperature of the gas? (3)

c. How much work was done by the gas during the isobaric process? (5)

d. An isothermal process is a thermodynamic process that doesn't change the number of moles or the temperature, but changes the pressure and volume. The gas from part b undergoes an isothermal process that takes it to 60 MPa. What is the new volume of the gas in liters? (3)

10. The Power of Ten

a. When given the sound intensity I, and reference sound intensity $I_0 = 1 \times 10^{-12}$ W/m^2, we can calculate the sound pressure level in dB using the equation $B = 10\log_{10}(I/I_0)$. What is the sound intensity for a car horn, measured to be at 110 dB? (3)

b. If we double the sound intensity from part a, what is the new sound pressure level? (3)

c. If we instead double the sound pressure level from part a, and have a sound of 220 dB, what is the new sound intensity? (3)

d. The acoustic power transmitted to a receiver by sound waves at a certain intensity can be found by multiplying the sound intensity by the area of the receiver. If a 220 dB blast of sound hits a 0.1 m^2 receiver for 0.5 milliseconds, how much energy is transmitted? (4)