General Physics I: Midterm Exam (114–1)

100 minutes, full mark = 50

It is **strictly forbidden** to use your notebooks/memos/books.
It is **strictly forbidden** to **have/wear/use** any electric devices, even in your pockets.
It is **strictly forbidden** to discuss with other students.

Administrative Remarks

- Use full-sized sheets for your answers. Smaller sheets are for calculation, not to submit.
- Write your name and student ID on the answer sheet. Put your student ID on the desk.
- Allowed on your desk: student ID card (required), pens/pencils, correction tools (eraser etc.), rulers, and drinks. **Other items must be stored in your bags.**
- You cannot wear watches nor electronic devices. **You cannot have them even in your pockets**.
- **After 13:10, the following actions are considered cheating. You may immediately lose your credit.**
  - If non-allowed items (pen cases, foods, poaches, etc.) are found on desks.
  - If you have textbooks, mobile phones, tablets, or PC, if they are not stored in your bags, or if you use them. They must be in your bags even after you submit your answer sheets.
- Breaks are not allowed in principle. After 14:00, you may leave after submission. In case of health problems or other issues, call the TA or lecturer.
- *Any form of academic dishonesty, including chats, additions/corrections after the period, and using your phones, will be treated by NSYSU "Academic Regulations."*

Scientific Remarks

- Show your calculations or thought process for **partial mark**!
- Use English, where mistakes are tolerated. Meanwhile, scientific mistakes are not tolerated.
  - Provide appropriate **units** properly.
  - Clearly distinguish **vectors** (by writing $\vec{E}$, $\vec{x}$ or $\mathbb{E}$, $\mathbb{x}$) from scalars (E, x).
- If you find any errors or issues in the questions, explain them on your answer sheet, make necessary adjustments on the question, and answer accordingly.
- You may use the following symbols and values without definition/declaration.

standard acceleration of gravity	g	$= 9.8\ \mathrm{m/s^2}$
Newtonian constant of gravitation	G	$= 6.7\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}$
elementary charge	e (or $\lvert e\rvert$)	$= 1.6\times10^{-19}\ \mathrm{C}$
permittivity of free space	ϵ_0	$= 8.9\times10^{-12}\ \mathrm{C^2\,N^{-1}\,m^{-2}}$
permeability of free space	$\mu_0 = \left(\epsilon_0 c^2\right)^{-1}$	$= \pi\times4.0\times10^{-7}\ \mathrm{N/A^2}$
Coulomb constant	$k_e = \left(4\pi\epsilon_0\right)^{-1}$	$= 9.0\times10^{9}\ \mathrm{N\cdot m^2/C^2}$
speed of light in vacuum	c	$= 3.0\times10^{8}\ \mathrm{m/s}$
Avogadro's number	N_A	$= 6.0\times10^{23}/\mathrm{mol}$
masses of protons and electrons	m_p, m_e	$= 1.7\times10^{-27}\ \mathrm{kg}$, $9.1\times10^{-31}\ \mathrm{kg}$

Unit vectors in the direction of the axes $(\vec{e_x}, \vec{e_y}, \vec{e_z})$ or $(\hat{e_x}, \hat{e_y}, \hat{e_z})$ or $(\hat{\imath}, \hat{\jmath}, \hat{k})$

$\vec{E}(\vec{x})$	electric field at $\vec{x}$	$\vec{B}(\vec{x})$	magnetic field (magnetic flux density) at $\vec{x}$
$V(\vec{x})$	electrostatic potential at $\vec{x}$	$\vec{F}_{XY}$	force exerted by X on Y

$\sqrt{2}\approx1.414$ $\sqrt{3}\approx1.732$ $\sqrt{5}\approx2.236$ $\sqrt{7}\approx2.646$ $\pi\approx3.142$ $\mathrm{e}\approx2.718$

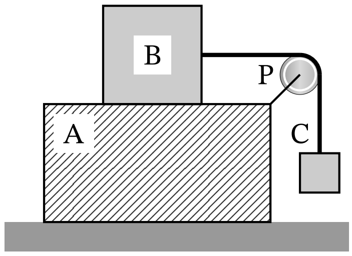
Answer **[Part I]** to **[Part IV]**. If you have done them with sufficient confidence, try **[Part V]**, a challenge from Sho.

[Part I] Mini Test Review (13 points)

- Calculate the following expressions.

  (A) $\dfrac{\mathrm{d}}{\mathrm{d}x}\sqrt{x-3}$ **(B)** $\dfrac{\mathrm{d}}{\mathrm{d}\theta}\sin^3\theta$ **(C)** $\dfrac{\mathrm{d}}{\mathrm{d}t}\dfrac{\ln(t-1)}{t-1}$

- Three blocks A, B, and C are arranged as in the right figure. Their masses are m_A, m_B, and m_C, respectively. A frictionless pulley P is attached to Block A, which is on the floor. Block B is put on Block A and connected to Block C by a light string that passes over the pulley. Block C is hanging vertically. All blocks are at rest.



  (D) We can find forces exerted on Block C. For each of them, describe its direction **in English words** and its magnitude with m_A, m_B, m_C, and g as needed.

  (E) We can find forces exerted on Block A. For each of them, describe its direction **in English words** and its magnitude with m_A, m_B, m_C, and g as needed.

  (F) Discuss what we can find about the coefficient of friction between blocks A and B.

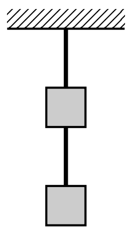
[Part II] Fundamental Problems (12 points)

- A 0.500 kg book is placed on a horizontal seat of your car. The coefficient of static friction between the book and the seat is 0.40 and that of kinetic friction is 0.35. You are traveling forward at 36.0 km/h and brake to a stop with constant acceleration, which takes 2.00 s. **(A)** Find the distance the car traveled during the 2.00 seconds. **(B)** Does the book slide on the seat during the braking? Answer with reason.

- Consider a satellite in a circular orbit around the Earth. Assume its mass is 1.0×10^3 kg, the circumference of the orbit is 1.0×10^5 km, and its period is 2.0×10^4 s. **(C)** Find its speed and angular speed. **(D)** Find the magnitude of the net force causing the centripetal acceleration.

- **(E)** Write the definition of instantaneous velocity.

[Part III] One-dimentional Motion (10 points)



As in the right figure, two cubes with an edge length of 3.0 cm are hanging in series from the ceiling by two strings. Both blocks have a mass of 0.10 kg. Both strings are 13 cm long and assumed to be massless and inextensible. Neglect air resistance.

At time $t=0$, an agent gently cuts the upper string. Both blocks then start to fall freely under the influence of gravity. The lower block hits the floor at $t=0.600$ s.

(A) Determine the tensions of both strings just before the upper string is cut.

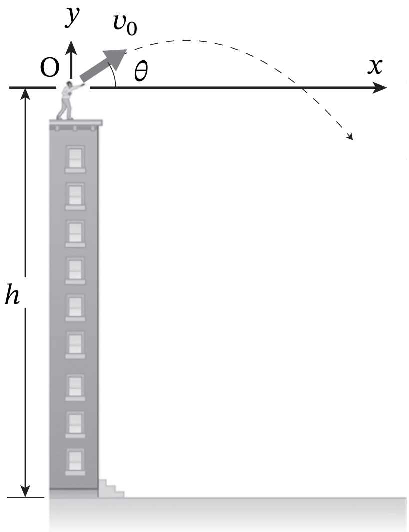
(B) Determine the direction and magnitude of the forces acting on the lower block during its fall.

(C) Find the velocity of the lower block just before hitting the floor.

(D) Immediately after hitting the floor, the lower block bounces back and starts moving upward with a speed of 0.12 m/s. Find when it hits the upper block.

[The exam questions continue on the next page.]

[Part IV] Two-dimensional Motion (15 points)

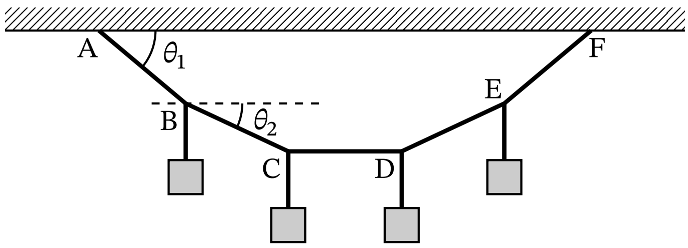


A man throws a stone of mass m from the top of a building upward at an angle θ to the horizontal with an initial speed v_0. The height from which the stone is thrown is h above the ground. Air resistance is negligible, and the magnitude of the gravitational acceleration is g.

As shown in the figure on the right, we take the point from which the stone is thrown as the origin O, and define x-axis rightward and y-axis upward. Assuming the stone is thrown at time $t = 0$, we express the position of the stone at time t as $\vec{r}(t) = \begin{pmatrix} x(t) \\ y(t) \end{pmatrix}$ and its velocity as $\vec{v}(t) = \begin{pmatrix} v_x(t) \\ v_y(t) \end{pmatrix}$.

- **(A)** Find $\vec{r}(0)$ and $\vec{v}(0)$.
- **(B)** Let $v(t)$ be the speed of the stone at time t. Express $v(t)$ by $v_x(t)$ and $v_y(t)$.
- **(C)** Express $x(t)$ and $y(t)$ by using v_0, θ, g, and t.
- **(D)** We define t_1 as the time when the stone reaches its highest point, t_2 as the time when it crosses the x-axis again, and t_3 as the time when it reaches the ground. Find t_1, t_2, and t_3.
- **(E)** We define two functions $K(t)$ and $U(t)$ as follows: $K(t) = \dfrac{m}{2}v(t)^2$ and $U(t) = mgy(t)$. Express them by using m, v_0, θ, g, and t.
- **(F)** Calculate $\dfrac{\mathrm{d}}{\mathrm{d}t}\Big[K(t) + U(t)\Big]$.

[Part V] Extra Challenge Problem (unlimited points)



As in the figure above, a string with a length L is suspended from the horizontal ceiling, with its two ends fixed at points A and F. The string is divided into five equal segments, and from each dividing point B, C, D, and E, a small object of mass m is suspended vertically downward by a string.

Let $l = L/5$ be the length of each segment (AB, BC, CD, DE, and EF), and d be the distance between A and F, where $d < L$. The angle between $\overrightarrow{\mathrm{AB}}$ and the horizontal is denoted by θ_1 and the angle between $\overrightarrow{\mathrm{BC}}$ and the horizontal is by θ_2. Answer the following questions, assuming all the strings are light and inextensible, the objects are point-like, and the ceiling is horizontal and rigid.

- **(A)** The middle segment CD is horizontal. Explain why.
- **(B)** Find the relation between θ_1 and θ_2.
- **(C)** Generalize this situation to the case with $2N$ objects, instead of four, where N is an integer with $N > 2$. The string should be equally divided into $2N + 1$ segments with $2N$ objects hanging from the dividing points. You will define $\theta_1, \ldots, \theta_N$ and find relations among them.

[This is the end of the exam questions.]