Physics 121 A
Autumn 2025

121A - BRAHMIA

Midterm 2
November 13th, 2025

Please use the boxes below to clearly print your name and UW NetID.
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I certify that the work I shall submit is my own creation, not copied from any source.

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Clearly fill out this cover page and the top portion of the provided bubble sheet with the necessary information.

Do not open the exam until told to do so.
When prompted, clearly print the information required at the top of each page of this exam booklet.

You can remove the equation sheet(s). Otherwise, keep the exam booklet intact. You will have 60 minutes to complete the examination.

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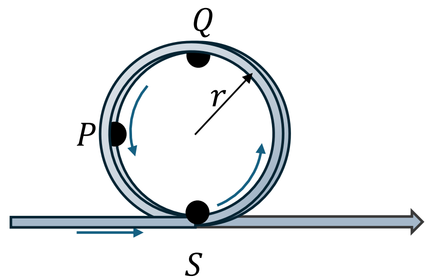
I. Lecture Multiple Choice [45 points – 9 questions]

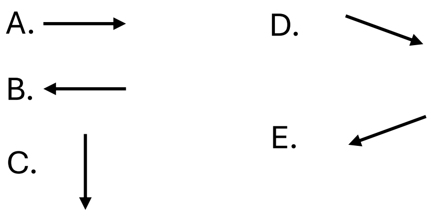
All questions have only one correct answer.

The figure at the right is for the next two questions.



An object is sliding with no friction around a circular loop of radius r. It enters at point S, travels counter-clockwise through points Q and P and then exits the loop again at point S.

1. [5 pts] At point P, the object is heading down the track and is speeding up. Which of these vectors could represent the net force on the object at point P?



2. [5 pts] What is the minimum speed that the object must have at point Q to stay on the track all the way around the loop? In the answers below,
$r =$ radius of the loop; $m =$ mass of the object; $g =$ gravitational acceleration.

   A. $\sqrt{5rg}$

   B. $2\sqrt{rg}$

   C. $\sqrt{rg}$

   D. $2mgr$

   E. $\sqrt{2rg}$

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3. [5 pts] A system has a potential energy described by: $U(r) = -B_o/r$, where r and B_o are both > 0. Which one of the following must be true:

   A. If $r_1 > r_2$, then $|U(r_1)| > |U(r_2)|$

   B. If $r_1 > r_2$, then $|F(r_1)| > |F(r_2)|$

   C. If $r_1 = 2r_2$, then $F(r_1) = 2F(r_2)$

   D. If $r_1 = 2r_2$, then $F(r_1) = \frac{1}{2} F(r_2)$

   E. If $r_1 = 2r_2$, then $F(r_1) = \frac{1}{4} F(r_2)$

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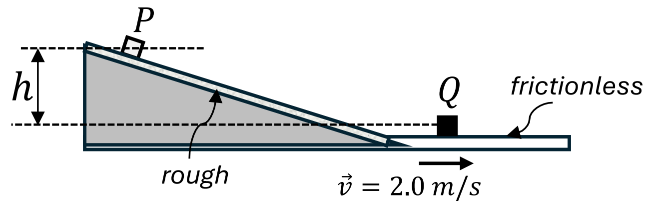
The sketch at the right is for the next two problems.

A block of mass 0.50 kg is released from rest at point P and the Earth-block-ramp system gains 4.0 J of thermal energy as the block slides from point P to point Q. The ramp is rough, and the horizontal surface at the base of the ramp is frictionless. The block has speed $v_Q = 2.0\ m/s$ as it passes through point Q.



4. [5 pts] What is h, the difference in height between points P and Q?

   A. 0.80 m

   B. 0.20 m

   C. 1.0 m

   D. 0.60 m

   E. Cannot determine without knowing the angle of the ramp.

5. [5 pts] The experiment is repeated by releasing a block of mass 1.0 kg from point P so that it slides to point Q. The 1.0 kg block and the 0.5 kg block have the same coefficients of friction (both static and kinetic). Which of the following statements is true about the experiment with the 1.0 kg block?

   A. The block's speed when it passes through Q is greater than 2.0 m/s.

   B. The block's speed when it passes through Q is less than 2.0 m/s.

   C. The block's speed when it passes through Q is equal to 2.0 m/s.

   D. We need to know the coefficient of friction and the angle of the ramp to compare the blocks' speeds when passing through Q.

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6. [5 pts] A constant net force, $\overrightarrow{F_{net}}$, is exerted on an object over a displacement $\overrightarrow{\Delta r}$. Which one of the following sets represents a possible combination of the quantities associated with the total work done on the object: the net force $\overrightarrow{F_{net}}$, the displacement $\overrightarrow{\Delta r}$, and the total work done on the object, W_{tot}?

   A. $\overrightarrow{F_{net}} = -10\text{ N}\,\hat{\imath}$ $\quad\overrightarrow{\Delta r} = +5\ m\ \hat{\jmath}$ $\quad W_{tot} = -50$ J

   B. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\quad\overrightarrow{\Delta r} = -2\ m\ \hat{\imath}$ $\quad W_{tot} = -20$ J

   C. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\quad\overrightarrow{\Delta r} = +4\ m\ \hat{\jmath}$ $\quad W_{tot} = -20$ J

   D. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\quad\overrightarrow{\Delta r} = +5\ m\ \hat{\imath}$ $\quad W_{tot} = -25$ J

   E. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\quad\overrightarrow{\Delta r} = +5\ m\ \hat{\imath}$ $\quad W_{tot} = +50$ J

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7. [5 pts] An object is moving along a line and slows down during a time interval of 0.1 seconds because it experiences a force. Which one of the following combinations of the initial momentum, p_{ix}, the final momentum, p_{fx} , and of the average force, $F_{ave,x}$, are possible if it slows down?

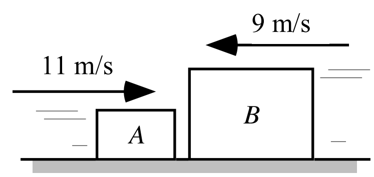
   A. $p_{ix} = +3\ \frac{\text{kg·m}}{s}$ $p_{fx} = +5\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=-20 N

   B. $p_{ix} = -5\ \frac{\text{kg·m}}{s}$ $p_{fx} = -3\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=+20 N

   C. $p_{ix} = +5\ \frac{\text{kg·m}}{s}$ $p_{fx} = +3\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=+20 N

   D. $p_{ix} = -3\ \frac{\text{kg·m}}{s}$ $p_{fx} = -5\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=-20 N

8. [5 pts] Block B has three times the mass of Block A. The two blocks move toward each other and collide head-on. Just before the collision, Block A is moving to the right at a speed of 11 m/s, and Block B is moving to the left at a speed of 9.0 m/s. If the blocks stick together after the collision, what is their velocity (magnitude and direction) immediately after impact?



   A. They will move to the left with a speed of 4.0 m/s.

   B. They will move to the left with a speed of 9.3 m/s.

   C. They will move to the right with a speed of 4.0 m/s.

   D. They will move to the right with a speed of 9.3m/s.

   E. Their velocities are equal to zero because both blocks stop after the collision.

9. [5 pts] A bundle of unexploded fireworks of total mass M moves horizontally along a frictionless track in the positive direction at a speed of 4.0 m/s. A small explosion occurs, splitting the bundle into two equal pieces. One piece continues moving in the positive direction, but at a speed of 16 m/s. What is the velocity (magnitude and direction) of the other piece immediately after the explosion?

   A. − 16 m/s

   B. + 16 m/s

   C. − 20 m/s

   D. − 8 m/s

   E. + 8 m/s

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II. Lab multiple-choice questions [15 points, 3 questions]

10. [5 pts] A group of students dropped a paper cup from above the top of a ladder. They decided it reached its terminal speed when it was at the top of the ladder. They repeated the experiment four times and measured the time it took for the cup to fall from the top of the ladder to the floor. What is the fractional uncertainty in the elapsed time?

Trial	Elapsed time (s)
1	2.15
2	2.23
3	2.16
4	2.20
Average	2.185
Standard deviation	0.037

A. 0.037 s
B. 0.037
C. 0.017 s
D. 0.017
E. 0.074

11. [5 pts] Another group of students did a similar experiment with a different paper cup. The average time, the distance and the associated uncertainties and fractional uncertainties are shown in the table. (The fractional uncertainty is the entire value shown on their calculator.)

	Average	**Uncertainty**	**Fractional uncertainty**
Time	4.5 s	0.3 s	0.06667
Distance	3.000 m	0.005 m	0.00167

What should the students report for the terminal speed of their paper cup based on the rules developed in lab for finding the uncertainty and significant figures?

A. 1.0 ± 0.1 m/s
B. 0.7 ± 0.1 m/s
C. 0.667 ± 0.002 m/s
D. 0.67 ± 0.07 m/s
E. 0.67 ± 0.04 m/s

12. [5 pts] A different group conducted an experiment to find out how the terminal speed depends on mass. For each trial, they dropped a cup and started their clock when the cup was moving at constant speed and was 3 m above the ground. They recorded the distance the cup fell in 2 s and repeated this measure four times. They followed this procedure for six measurements, using six identically shaped cups with a different mass for each measurement. In their exploration of how the terminal speed depends on the mass of the cup, what are the independent and the dependent quantities?

	Independent	**Dependent**	**Control**
A.	Distance	Time	Mass
B.	Time	Distance	Mass
C.	Mass	Distance	Time
D.	Mass	Time	Distance
E.	Distance	Mass	Time

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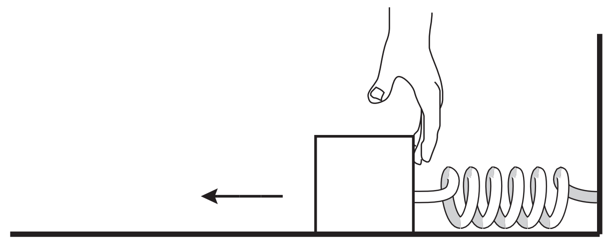
III. Lecture free-response questions [25 points]

Use the following scenario for the next two questions.

A block of mass $m = 2.0\ kg$ is attached to an ideal spring with spring constant k = 24.0 N/m, the other end of which is attached to a rigid wall. At t = 0 s, the spring is at its equilibrium length and the block has kinetic energy $K = 1.2\ J$. At that instant, a student starts pushing the block with a constant horizontal force F = 9.0 N in the direction of the block's motion.



13. [6 pts] The student assumes the friction in the block-spring-surface system is negligible. What is their prediction for the kinetic energy of the block after they have pushed it a distance d = 0.4 m?

Predicted final kinetic energy =

14. [7 pts] The student conducts the experiment and finds that the kinetic energy of the block is 0.19 J *less* than they predicted. Determine the coefficient of kinetic friction between the block and the surface.

Coefficient of kinetic friction =

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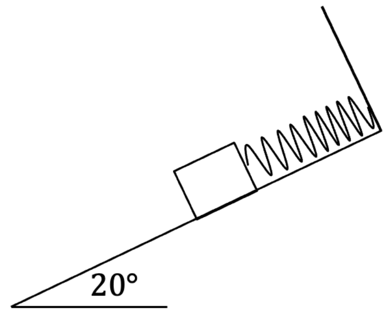
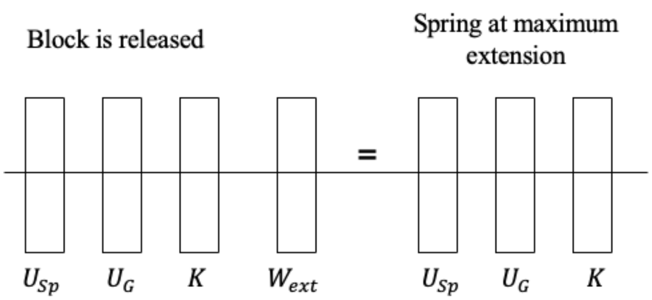
Use the following scenario for the next two questions.



A block of mass m = 1.2 kg is attached to an ideal spring with spring constant k = 32.0 N/m. The block can slide with negligible friction along a 20-degree ramp, as shown.
At t = 0 s, the block is released from rest when the spring is neither stretched nor compressed.

15. [6 pts] Complete the energy bar charts below for the system of the block, spring and Earth for the instant the block is released, and the instant the spring reaches its maximum extension.



16. [6 pts] What is the maximum distance the block travels along the ramp?

Maximum distance =

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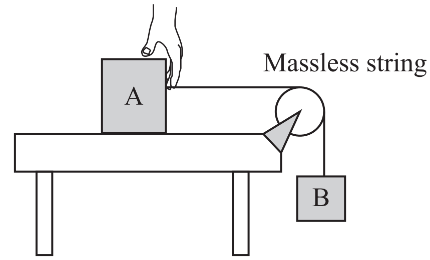
IV. Tutorial free-response questions [15 points]

The next two questions are based on the description below.

Block A, on a level, frictionless table, is attached to a massless string that passes over an ideal, frictionless pulley. The other end of the string is attached to block B. At t_o, Block A is released. The mass of block B is less than that of block A.



After t_o but before block B hits the ground:

17. [5 pts] Is the magnitude of the acceleration of block A *greater than, less than,* or *equal to* the magnitude of the acceleration of block B? Explain.

18. [5 pts] Is the magnitude of the force on block A by the string *greater than, less than,* or *equal to* the magnitude of the gravitational force on block B by the Earth? Explain.

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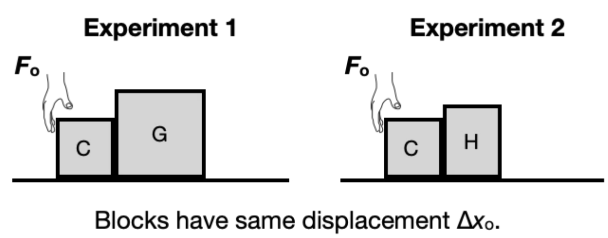
19. [5 pts] In experiment 1 blocks C and G are pushed to the right on a table by a constant force $\boldsymbol{F}_o$, as shown.

In Experiment 2 block G is replaced by a block of less mass, block H. The same constant force $\boldsymbol{F}_o$ is applied to block C. In both cases, the blocks have the same displacement, Δx_o.



Is the total external work done on the system that includes only block C in experiment 1 ($W_{\text{tot ext, C1}}$) *greater than, less than,* or *equal to* the total external work done on that system in experiment 2 ($W_{\text{tot ext, C2}}$)? Explain.

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Constants

Free-fall acceleration	$g = 9.80\ \mathrm{m/s^2}$
Gravitational constant	$G = 6.67 \times 10^{-11}\mathrm{N\,m^2/kg^2}$

Mathematics

Vector components	$\vec{A} = \vec{A}_x + \vec{A}_y = A_x\hat{\imath} + A_y\hat{\jmath}$
Vector magnitude	$A = \sqrt{A_x^2 + A_y^2}$
θ ccw from x-axis	$A_x = A\cos\theta$ $A_y = A\sin\theta$ $\theta = \tan^{-1}(A_y/A_x)$
Adding vectors $\vec{C} = \vec{A} + \vec{B}$	$C_x = A_x + B_x$ $C_y = A_y + B_y$
Dot product	$\vec{A}\cdot\vec{B} = AB\cos\alpha$ $\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y$
Cross product	$\lvert\vec{A}\times\vec{B}\rvert = AB\sin\alpha$ $\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$
Standard deviation	$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{\mathrm{ave}})^2}{n-1}}$

Linear motion

Average velocity	$\vec{v}_{\mathrm{ave}} \equiv \frac{\Delta\vec{r}}{\Delta t} = \frac{\vec{r}_{\mathrm{f}} - \vec{r}_{\mathrm{i}}}{t_{\mathrm{f}} - t_{\mathrm{i}}}$
Instantaneous velocity	$\vec{v} = \frac{d\vec{r}}{dt}$
Instantaneous acceleration	$\vec{a} = \frac{d\vec{v}}{dt}$

Constant acceleration (in "s" direction)

$$v_{\mathrm{f}s} = v_{\mathrm{i}s} + a_s\Delta t$$
$$s_{\mathrm{f}} = s_{\mathrm{i}} + v_{\mathrm{i}s}\Delta t + \tfrac{1}{2}a_s(\Delta t)^2$$
$$v_{\mathrm{f}s}^2 = v_{\mathrm{i}s}^2 + 2a_s\Delta s$$

Motion on inclined plane	$a_s = \pm g\sin\theta$
Relative motion	$\vec{v}_{\mathrm{CB}} = \vec{v}_{\mathrm{CA}} + \vec{v}_{\mathrm{AB}}$

Circular motion

Angular position	$\theta = \frac{s}{r}$
Angular velocity	$\omega = \frac{d\theta}{dt}$
Angular acceleration	$\alpha = \frac{d\omega}{dt}$
Tangential velocity	$v_t = \omega r$
Centripetal acceleration	$a_r = \frac{v_t^2}{r} = \omega^2 r$
Tangential acceleration	$a_t = \alpha r$
Period	$T = \frac{2\pi r}{v} = \frac{2\pi}{\omega}$
Const. angular acceleration	$\omega_{\mathrm{f}} = \omega_{\mathrm{i}} + \alpha\Delta t$ $\theta_{\mathrm{f}} = \theta_{\mathrm{i}} + \omega_{\mathrm{i}}\Delta t + \frac{1}{2}\alpha(\Delta t)^2$ $\omega_{\mathrm{f}}^2 = \omega_{\mathrm{i}}^2 + 2\alpha\Delta\theta$

Force and motion

Newton's 2nd law	$\vec{a} = \frac{\vec{F}_{\mathrm{net}}}{m}$
Gravity	$F_{\mathrm{G}} = mg$ $F_{\mathrm{G}} = \frac{GMm}{R^2}$
Maximum static friction	$f_{\mathrm{s\,max}} = \mu_{\mathrm{s}}n$
Kinetic friction	$f_{\mathrm{k}} = \mu_{\mathrm{k}}n$
Reynolds number	$Re = \frac{\rho vL}{\eta}$
Drag (high Re)	$F_{\mathrm{drag}} = \frac{1}{2}C_{\mathrm{d}}\rho Av^2$
Drag (low Re)	$F_{\mathrm{drag}} = 6\pi\eta rv$
Newton's 3rd law	$\vec{F}_{\mathrm{A\,on\,B}} = -\vec{F}_{\mathrm{B\,on\,A}}$
Circular motion	$(F_{\mathrm{net}})_r = \frac{mv_t^2}{r} = m\omega^2 r$ $(F_{\mathrm{net}})_t = ma_t$

Work and energy

Kinetic energy	$K = \frac{1}{2}mv^2$
Work by a constant force	$W = \vec{F}\cdot\Delta\vec{r}$
Hooke's law	$(F_{\mathrm{Sp}})_s = -k\Delta s$
Work done by a spring	$W = -\frac{1}{2}k[(\Delta s_{\mathrm{f}})^2 - (\Delta s_{\mathrm{i}})^2]$
Dissipative force	$\Delta E_{\mathrm{th}} = f_{\mathrm{k}}\Delta s$
Potential energy	$\Delta U = -W_{\mathrm{int}}$
Grav. potential energy	$U_{\mathrm{G}} = mgy$
Elastic potential energy	$U_{\mathrm{Sp}} = \frac{1}{2}k(\Delta s)^2$
Mechanical energy	$\Delta E_{\mathrm{mech}} = \Delta K + \Delta U$
System energy	$\Delta E_{\mathrm{sys}} = \Delta E_{\mathrm{mech}} + \Delta E_{\mathrm{th}}$ $\Delta E_{\mathrm{sys}} = W_{\mathrm{ext}}$

Power $P = \frac{dE_{\text{sys}}}{dt}$

$P = \vec{F} \cdot \vec{v}$

Force and potential energy $F_s = -\frac{dU}{ds}$

Impulse and linear momentum

Momentum $\vec{p} = m\vec{v}$

Impulse $\vec{J} \equiv \int_{t_\text{i}}^{t_\text{f}} \vec{F}(t)dt$

Momentum principle $\Delta\vec{p} = \vec{J}$

Isolated system $\vec{P}_\text{f} = \vec{P}_\text{i}$

Force $\vec{F} = \frac{d\vec{p}}{dt}$

Elastic collision with $(v_{\text{i}x})_2 = 0$

$$(v_{\text{f}x})_1 = \frac{m_1 - m_2}{m_1 + m_2}(v_{\text{i}x})_1$$

$$(v_{\text{f}x})_2 = \frac{2m_1}{m_1 + m_2}(v_{\text{i}x})_1$$

Rotation

Center of mass $x_{\text{cm}} = \frac{1}{M}\sum_i m_i x_i$

Moment of inertia $I = \sum_i m_i r_i^2$

- Rod (center) $\frac{1}{12}ML^2$
- Rod (end) $\frac{1}{3}ML^2$
- Disk $\frac{1}{2}MR^2$
- Hoop MR^2
- Solid sphere $\frac{2}{5}MR^2$
- Hollow sphere $\frac{2}{3}MR^2$

Parallel-axis theorem $I = I_{\text{cm}} + Md^2$

Rotational kinetic energy $K_{\text{rot}} = \frac{1}{2}I\omega^2$

Torque $\tau \equiv rF\sin\phi = rF_\perp = Fd$

$\vec{\tau} \equiv \vec{r} \times \vec{F}$

Gravitational torque $\tau_{\text{grav}} = -Mgx_{\text{cm}}$

Newton's second law for rotation

$$\alpha = \frac{\tau_{\text{net}}}{I}$$

Critical angle $\theta_\text{c} = \tan^{-1}\left(\frac{t}{2\text{h}}\right)$

Rolling $v_{\text{cm}} = R\omega$

$K_{\text{rolling}} = \frac{1}{2}I_{\text{cm}}\omega^2 + \frac{1}{2}Mv_{\text{cm}}^2$

Angular momentum $\vec{L} \equiv \vec{r} \times \vec{p}$

Angular momentum of a particle

$$L_z = mrv_t = mr^2\omega$$

Angular momentum of a rigid body

$$\frac{d\vec{L}}{dt} = \vec{\tau}_{\text{net}}$$

$$\vec{L} = I\vec{\omega}$$

Theory of gravity

Law of gravity $F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{Gm_1m_2}{r^2}$

Free-fall acceleration $g = \frac{GM}{r^2}$

Potential energy $U_\text{G} = -\frac{Gm_1m_2}{r}$

Satellite speed $v = \sqrt{\frac{GM}{r}}$

Kepler's third law $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$

Escape speed $v_{\text{escape}} = \sqrt{\frac{2GM}{R}}$

Geosynchronous orbit $r_{\text{geo}} = \left(\frac{GM}{4\pi^2}T^2\right)^{1/3}$