Please remove this sheet before starting your exam.

Things you must have memorized

The Momentum Principle	The Energy Principle	The Angular Momentum Principle
Definitions of: velocity, momentum, particle energy, kinetic energy, work, angular velocity, angular momentum, torque		

Other useful formulas

$$\gamma \equiv \frac{1}{\sqrt{1-(|\vec{v}|^2/c^2)}} \qquad E^2-(pc)^2=\left(mc^2\right)^2$$

$$\vec{F}_{\text{grav}} =< 0, -mg, 0 > \qquad \Delta U_{\text{grav}} = mg\Delta y$$

$$\vec{F}_{\text{grav}} = G\frac{m_1 m_2}{|\vec{r}|^2}(-\hat{r}) \qquad U_{\text{grav}} = -G\frac{m_1 m_2}{|\vec{r}|}$$

$$\vec{F}_{\text{electric}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}|^2}\hat{r} \qquad U_{\text{electric}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}|}$$

$$\vec{F}_{\text{spring}} = -k_s(|\vec{L}|-L_0)\hat{L} \qquad U_{\text{spring}} = \frac{1}{2}k_s s^2$$

$$\vec{r}_f = \vec{r}_i + \vec{v}_i\Delta t + \frac{1}{2}\frac{\vec{F}_{\text{net}}}{m}(\Delta t)^2 \qquad \Delta E_{\text{thermal}} = mC\Delta T$$

$$\frac{d\vec{p}}{dt} = \frac{d|\vec{p}|}{dt}\hat{p} + |\vec{p}|\frac{d\hat{p}}{dt} \qquad \vec{F}_{\parallel} = \frac{d|\vec{p}|}{dt}\hat{p} \text{ and } \vec{F}_{\perp} = |\vec{p}|\frac{d\hat{p}}{dt} = |\vec{p}|\frac{|\vec{v}|}{R}\hat{n}$$

$$\vec{r}_{\text{cm}} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + \ldots}{m_1 + m_2 + \ldots} \qquad I = m_1 r_{1\perp}^2 + m_2 r_{2\perp}^2 + \ldots$$

$$K_{\text{tot}} = K_{\text{trans}} + K_{\text{rel}} \qquad K_{\text{rel}} = K_{\text{rot}} + K_{\text{vib}}$$

$$K_{\text{rot}} = \frac{L_{\text{rot}}^2}{2I} \qquad K_{\text{rot}} = \frac{1}{2}I\omega^2$$

$$\vec{L}_A = \vec{L}_{\text{trans,A}} + \vec{L}_{\text{rot}} \qquad \vec{L}_{\text{rot}} = I\vec{\omega}$$

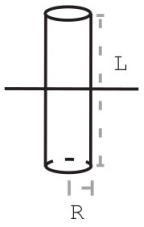
$$Y = \frac{F/A}{\Delta L/L} \text{ (macro)} \qquad Y = \frac{k_{si}}{d} \text{ (micro)}$$

$$\omega = \sqrt{\frac{k_s}{m}} \qquad E_N = -\frac{13.6\text{eV}}{N^2} \text{ where } N = 1, 2, 3\ldots$$

The cross product

$$\vec{A}\times\vec{B} = \langle A_yB_z - A_zB_y,\ A_zB_x - A_xB_z,\ A_xB_y - A_yB_x\rangle$$

Moment of inertia for rotation about indicated axis

				
$I = \frac{2}{5}MR^2$	$I = \frac{1}{2}MR^2$	$I = \frac{1}{12}ML^2$	$I = \frac{1}{3}ML^2$	$I = \frac{1}{12}ML^2 + \frac{1}{4}MR^2$

Constant	**Symbol**	**Approximate Value**
Speed of light	c	3×10^8 m/s
Gravitational constant	G	6.7×10^{-11} N $\cdot$ m^2/kg^2
Grav accel near Earth's surface	g	9.8 m/s^2
Electron mass	m_e	9×10^{-31} kg
Proton mass	m_p	1.7×10^{-27} kg
Neutron mass	m_n	1.7×10^{-27} kg
Electric constant	$\frac{1}{4\pi\epsilon_0}$	9×10^9 N $\cdot$ m^2/C^2
Proton charge	e	1.6×10^{-19} C
Electron volt	1 eV	1.6×10^{-19} J
Avogadro's number	N_A	6.02×10^{23} atoms/mol
Plank's constant	h	6.6×10^{-34} J $\cdot$ s
hbar $= \frac{h}{2\pi}$	$\hbar$	1.05×10^{-34} J $\cdot$ s
specific heat capacity of water	C	4.2 J/(g $\cdot$ °C)

milli	m	1×10^{-3}	kilo	k	1×10^3
micro	μ	1×10^{-6}	mega	M	1×10^6
nano	n	1×10^{-9}	giga	G	1×10^9
pico	p	1×10^{-12}	tera	T	1×10^{12}

PHYS 2211 - Summer 2024 - Test 3

Name: _____ GTID: _____

Instructions

- This quiz/test/exam is closed internet, books, and notes.
  - You are allowed to use the Formula Sheet that is included with the exam.
  - You are allowed to use a calculator as long as it cannot connect to the internet.
  - You must join the appropriate proctoring meeting in MS Teams and keep your camera on and microphone muted throughout the exam period.
  - Other than MS Teams and Gradescope (and a PDF annotation app if applicable), you must not access any other app or website during the exam.
  - You must work individually and receive no assistance from any person or resource.
- You are not allowed to share or post information, screenshots, files, or any other details of the test anywhere online, not even after the test is over, except for uploading your work to Gradescope for grading.
- Work through all the problems first, then **scan and upload your solutions to Gradescope** after time is called.
  - You should upload **one single PDF file** to the test assignment on Gradescope.
  - You **must** indicate which page corresponds to each problem or sub-part when you upload your work.
  - Make sure your file is readable. Unreadable files will not be graded and will earn a score of zero.
  - Clearly label your work for each sub-part and box the final answers.
- To earn partial credit, your work must be legible and the organization must be clear.
  - Your solutions should be worked out algebraically (i.e., symbolically).
  - Numerical solutions should only be evaluated (i.e., plug in numbers) at the last step.
  - You must show all your work, including correct vector notation.
  - **Correct answers without adequate explanation will be marked as incorrect.**
  - Incorrect work or explanations mixed in with correct work will be marked as incorrect. Cross out anything you do not want us to grade.
  - Make explanations correct but brief. You do not need to write a lot of prose.
  - Include diagrams and show what goes into a calculation, not just the final number. For example: $\frac{a \cdot b}{c \cdot d} = \frac{(8 \times 10^{-3})(5 \times 10^{6})}{(2 \times 10^{-5})(4 \times 10^{4})} = 5 \times 10^{4}$
  - Give standard SI units with your numerical results. Symbolic answers should not have units.

Unless specifically asked to derive a result, you may start from the formulas given on the Formula Sheet, including equations corresponding to the fundamental concepts. If a formula you need is not given, you must derive it. If you cannot do a portion of a problem, invent a symbol for the quantity you cannot calculate (explain that you are doing this), and use it to do the rest of the problem.

**"In accordance with the Georgia Tech Honor Code,
I have completed this test while adhering to these instructions."**

_____

Sign your name on the line above

Rotating Reel [30 pts]

A reel consists of a cylinder of radius R and mass $6M$ with 4 very small (i.e. point) masses M attached at the outer rim of the cylinder (see Figure 1). A reel can freely rotate around a fixed axis through its center. A light rope is wound around the cylinder. At the initial state the reel is motionless. Then a force of constant magnitude F is applied to the rope. At the final state the rope is unwound distance b while the reel acquires angular speed ω (see Figure 2).

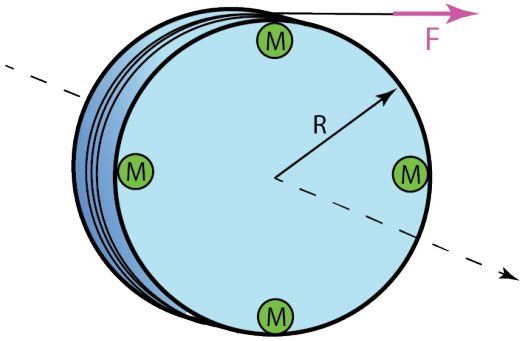


Figure 1. Initial state

Answer all questions in this problem in terms of known quantities R, M, F, b.

1. [10 pts] Determine the total moment of inertia I of the reel.

2. [20 pts] Determine the angular speed ω of the reel at the final state.

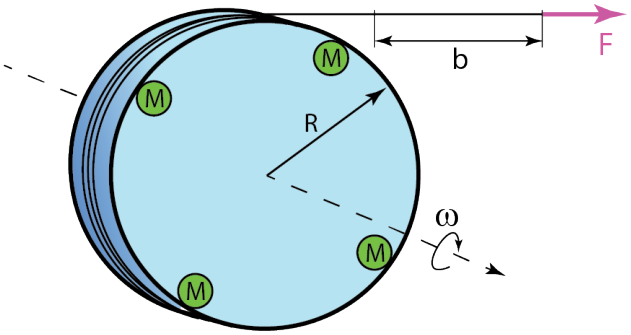


Figure 2. Final state

Center of Mass [30 pts]

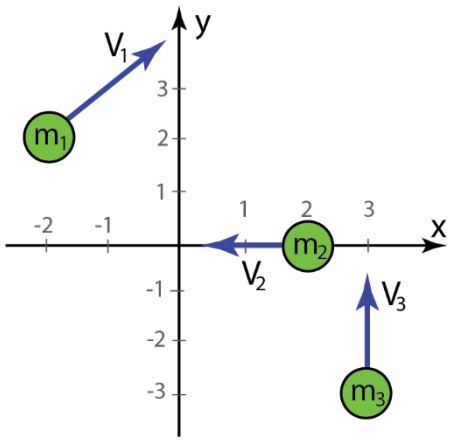
Three small particles have masses $m_1 = 7.0\ kg,\ m_2 = 5.0\ kg$, and $m_3 = 8.0\ kg$ and are located at

$\vec{r}_1 = \langle -2.0, 2.0, 0.0 \rangle m,\ \vec{r}_2 = \langle 2.0, 0.0, 0.0 \rangle m,$ and $\vec{r}_3 = \langle 3.0, -3.0, 0.0 \rangle m.$

Velocities of these particles are:

$\vec{v}_1 = \langle 5.0, 4.0, 0.0 \rangle m/s,\ \vec{v}_2 = \langle -3.0, 0.0, 0.0 \rangle m/s,$ and $\vec{v}_3 = \langle 0.0, 4.0, 0.0 \rangle m/s.$

1. [8 pts] Find the position $\vec{r}_{CM}$ of the center of mass of this system.



2. [8 pts] Find the velocity $\vec{V}_{CM}$ of the center of mass of this system.

3. [4 pts] Find the translational kinetic energy K_{trans} of this system.

4. [8 pts] Find the total kinetic energy K_{tot} of this system.

5. [2 pts] Find the kinetic energy of this system relative to the center of mass K_{rel}.

Projectile Launch [40 pts]

A projectile (rocket) of mass m is launched from the surface of the Earth with the initial speed $V_i = \sqrt{\frac{5GM}{3R}}$ where G is the universal gravitational constant, M is the mass of the Earth, and R is its radius (see Figure 1).

1. [10 pts] Determine the total energy of the projectile in the initial state (at the launch time, Figure 1). Express your answer in terms of known quantities G, M, m, R.

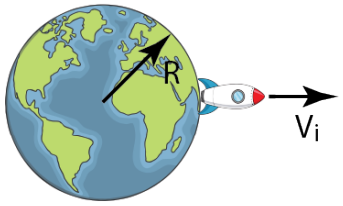


Figure 1. Initial state

2. [10 pts] At the final state the projectile is at the maximum height h relative to the Earth's surface and is momentarily at rest (see Figure 2). Express the total energy of the projectile in the final state in terms of given quantities and h.

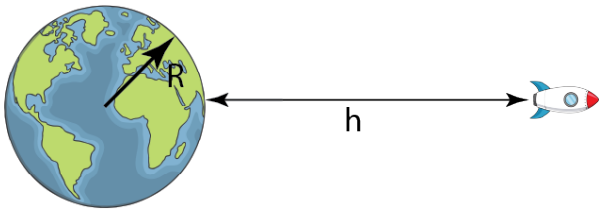


Figure 2. Final state

3. [10 pts] Determine the maximum height h of the projectile relative to the Earth's surface in terms of R.

4. [10 pts] Sketch the gravitational potential energy and the total energy of the projectile between initial and final states as a function *of the distance to the center of the Earth* r on the provided graph.