**Physics 105 Final Examination**
January 26, 2006

This exam consists of **seven** problems. When we begin, check to see that this copy of the exam has all seven. Use the same exam booklet for all problems, continuing to another booklet if necessary. **Print** your name on **each** booklet as you start it. On the cover of your first booklet, **COPY** and **SIGN** the following pledge:

*I pledge my honor that I have not violated the Honor Code during this examination.*

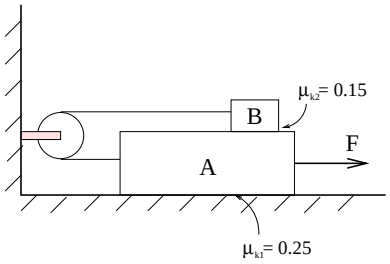
At the end of the exam, indicate clearly on the cover of your first exam booklet how many booklets you used.

Some useful test-taking hints:

- You may not be able to complete every problem. Keep moving – do what you know first.
- Make your answer clear by circling it.
- Use symbols rather than numbers wherever possible and check units.
- Whenever possible, check whether an answer or intermediate result makes sense before moving on.
- There is a list of formulas on a page you can tear out attached to the exam. Use it as a reminder of details. Don't try to do problems by searching through the sheet!
- If you get stuck on an early part of a problem, check the later parts — some may be independent and doable.
- If you get stuck on an early part of a problem, and a later part depends on it, **clearly** define a symbol for the unknown answer and use it in later parts. Note: this is an act of desperation – we often give multiple parts to guide you through a problem.
- **Show your work!**

**The exam will last 3 hours.**
**Good luck!**

**1. Sliding Blocks.** [30 pts] Two blocks of mass $m_A = 20\,\text{kg}$ and $m_B = 5\,\text{kg}$ are connected by a massless cable wound around a massless pulley. A force $\mathbf{F}$ is applied to block A causing it to slide over a horizontal surface with kinetic coefficient of friction $\mu_1 = 0.25$, while block B slides over block A with $\mu_2 = 0.15$.

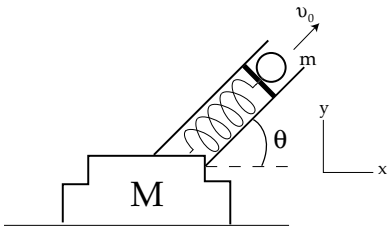



a. [20 pts] What force is needed to move the blocks with constant speed?

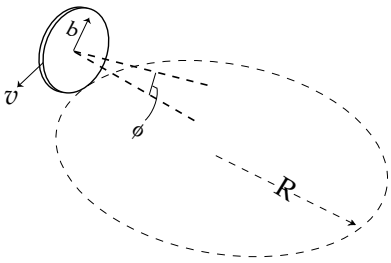
b. [5 pts] If the cable can sustain a maximum tension of 100 N, what is the maximum force $\mathbf{F}_{\max}$ allowable without breaking the cable? Note that we now let the block accelerate.

c. [5 pts] Assuming $\mathbf{F} = \mathbf{F}_{\max}$, what fraction of the work done by $\mathbf{F}$ is lost due to friction?

**2. Spring Gun.** [20 pts] A loaded spring gun of mass $M$ is initially at rest on a frictionless table. The gun is cocked as shown in the figure, so that when a marble of mass $m$ is fired, its muzzle velocity $v_0$ makes an angle $\theta$ to the horizontal. (Muzzle velocity is measured relative to the gun.) What is the final motion of the gun?

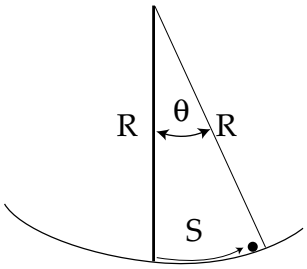



**3. Rolling Coin.** [20 pts] A coin of radius $b$ rolls on a horizontal surface without slipping in a circle of radius $R >> b$ with speed $v$. As indicated in the sketch, the axis of the coin makes an angle $\phi$ with the horizontal such that the coin is tilted toward the center of circle.




What is the angle $\phi$ in terms of $v$, $g$, and $R$? Recall that the moment of inertia of the coin is $I = mb^2/2$.

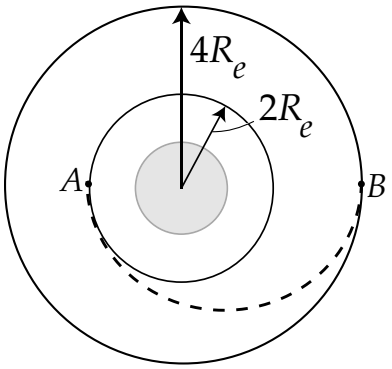
**4. Rolling ball.** [20 pts] A ball bearing of mass $m$ and radius $b$ is held against the inside wall of a spherical bowl of radius $R$ at some height above the bottom of the bowl. It is then released and rolls without slipping toward the bottom of the bowl. You may assume $b << R$.



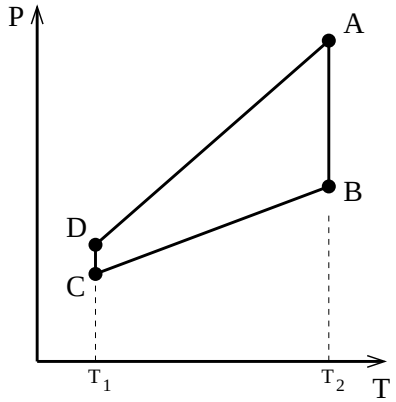

a. [15 pts] What is the equation of motion of the ball in terms of the distance, $s$, along the inside surface of the bowl? It may help to recall that $s = R\theta$ where $\theta$ is measured as shown below and that the moment of inertia of a sphere about an axis through its center is $I = 2mb^2/5$. Your equation should be valid for $-\pi/2 < \theta < \pi/2$.

b. [5 pts] What is the period of oscillation for small displacements from the bottom of the bowl?

**5. Hohmann Transfer.** [20 pts] A satellite is in a circular orbit around the Earth. Its mass is $m_s$ and the radius of the orbit is $2R_e$ as shown. Mission control wants to transfer the satellite to a new orbit with $R_{new} = 4R_e$ along an elliptical orbit. What velocity change, magnitude and direction, is required at the point marked A?



**6. Reversible Engine.** [20 pts] A reversible engine containing one mole of an ideal monatomic gas proceeds through the cycle $A \rightarrow B \rightarrow C \rightarrow D$ indicated on the P-T graph below. The entire cycle operates between a cold reservoir at temperature $T_1$ and a hot reservoir at temperature $T_2$.




a. [5 pts] Sketch the cycle in the P-V plane and identify the processes associated with each segment of the cycle. The functional form P(V) for each segment should be clear from your graph.

b. [10 pts] What is the efficiency of the engine in terms of $T_1$, $T_2$, $V_A$, and $V_B$?

c. [5 pts] Show explicitly that the efficiency of this engine is less than the efficiency of a Carnot engine operating between $T_1$ and $T_2$.

**7. Relativity.** [20 pts] In the lab you arrange for two flashbulbs to light up. The first flashes at time $t_A = 0$ and position $x_A = 480$ m and the second flashes at time $t_B = 5$ $\mu$s and $x_B = 1200$ m. Your friend flies by this arrangement in a rocket traveling at $v$ in the $+x$ direction. To him, the flashes occur at the same place but at different times. What is the difference in time between flashes that he measures (in seconds)?