Problem 1 (46 points) A planet of mass $M$ is orbited by two identical moons, each of mass $M/3$. The two moons both follow the same orbit or radius $r$ around the planet, and are always on opposite sides of the planet. Each moon experiences a gravitational force from the planet and a gravitational force from the other moon.

(a) Find the magnitude of the net gravitational force exerted on either moon by the planet and the other moon. Your answer should involve no quantities other than $M$, $G$, and $r$. (It may or may not involve all of these quantities. You will lose points if you substitute a numerical value for $G$.) For full credit, show your work, simplify your answer, and draw a box around your final answer.
Problem 1 (continued)

(b) **Find the orbital period of either moon.** Your answer should involve no quantities other than $M$, $G$, and $r$. (It may or may not involve all of these quantities. You will lose points if you substitute a numerical value for $G$.) For full credit, **show your work, simplify your answer, and draw a box around your final answer.**
Problem 2 (30 points) A solid, uniform cylinder of mass $M$ and radius $R$ is surrounded by a thin hoop of the same mass $M$ and radius $R$. The cylinder and hoop are glued together. The cylinder-hoop combination is placed on a ramp inclined at an angle $\theta$ from the horizontal. When released, the cylinder-hoop combination rolls down the ramp without slipping.

Possibly useful information:
- Moment of inertia of a uniform cylinder of mass $M$ and radius $R$ around its center: $I = \frac{1}{2}MR^2$
- Moment of inertia of a uniform cylinder of mass $M$ and radius $R$ around its rim: $I = \frac{3}{2}MR^2$
- Moment of inertia of a hoop of mass $M$ and length $R$ around its center: $I = MR^2$
- Moment of inertia of a hoop of mass $M$ and length $R$ around its rim: $I = 2MR^2$
- Number of syllables in the word “sesquipedalian”: six

Find the magnitude and direction of the friction force acting on the system of cylinder and hoop. Your answer should involve no quantities other than $M$, $R$, $g$, and $\theta$. (It may or may not involve all of these quantities. You will lose points if you substitute a numerical value for $g$.) For full credit, show your work, simplify your answer, state whether the friction force points up or down the ramp, and draw a box around your final answer.
Multiple-choice questions (24 points). For each of these three questions, mark a clear “X” in the box next to the correct answer.

1. A rock, initially at rest with respect to Earth and located very far away, is released and accelerates toward Earth. An observation tower is built 3 Earth radii high to observe the rock as it plummets to Earth. Neglecting friction, the rock’s speed when it hits the ground is

- (a) twice as fast as when it passed the top of the tower.
- (b) 3 times as fast as when it passed the top of the tower.
- (c) 4 times as fast as when it passed the top of the tower.
- (d) 8 times as fast as when it passed the top of the tower.
- (e) 16 times as fast as when it passed the top of the tower.

2. A 72.0-kg person pushes on a small doorknob with a force of 5.00 N perpendicular to the surface of the door. The doorknob is located 0.800 m from axis of the frictionless hinges of the door. The door begins to rotate with an angular acceleration of \(2.00 \text{ rad/s}^2\). What is the moment of inertia of the door about the hinges?

- (a) 2.74 kg\cdot m^2
- (b) 1.88 kg\cdot m^2
- (c) 4.28 kg\cdot m^2
- (d) 0.684 kg\cdot m^2
- (e) 7.52 kg\cdot m^2

3. A very light 1.00-m wire consists of two segments of equal length, one of steel (Young's modulus is \(2.00 \times 10^{11} \text{ N/m}^2\)) and one of brass (Young's modulus is \(9.0 \times 10^{10} \text{ N/m}^2\)). The steel segment is 1.50 mm in diameter, and the brass segment has twice this diameter. When a weight \(w\) is hung from the ceiling by this wire, the steel segment stretches by 1.10 mm. Find the value of the weight \(w\).

- (a) 1000 N
- (b) 390 N
- (c) 780 N
- (d) 3100 N
- (e) 190 N