

INSTRUCTIONS: Write your NAME and your SECTION (01: 8:30/Eskildsen, 02: 3:00/Tang) on the front of the blue exam booklet. The exam is closed book, and in addition to the equation compendium only pens/pencils and a calculator (no stored equations or programs and no graphing) may be used.

The distributed compendium must be returned at the end of the exam. Please do not write in it.

For problems II-VII you must write the complete solution in your blue book. No credit (full or partial) will be given for an answer without supporting work. Draw a diagram when possible, circle or box your final answers, and cross out parts which you do not want us to consider.

I. Multiple Choice Questions (4 points each)

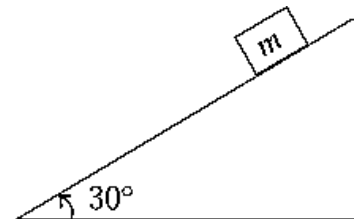
Read each question carefully. Write the *single* correct answer in the grid on the first page inside your blue book. No explanation is required, and no partial credit will be given.

MC1. A physical quantity that is sometimes described as the measure of the resistance of a body to a change in motion is:

- A) Force
- B) Mass
- C) Acceleration
- D) Weight
- E) Friction

MC2. A block of mass m is at rest on an inclined plane that makes an angle of 30° with the horizontal, as shown in the figure. Which of the following statements about the magnitude of the static friction force is true?

- A) $f_s > mg$
- B) $f_s > mg \cos 30^\circ$
- C) $f_s = mg \cos 30^\circ$
- D) $f_s > mg \sin 30^\circ$
- E) $f_s = mg \sin 30^\circ$



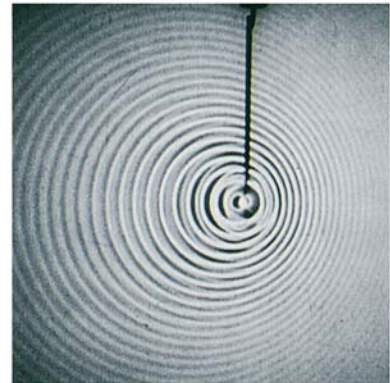
- MC3. A block slides a certain distance down an incline. During the descent the work done by friction is $-|W|$. What is the work done by friction if the block is pushed the same distance up the incline by a force parallel to the surface?
- A) Zero
 - B) $|W|$
 - C) $-|W|$
 - D) Friction cannot do work.
 - E) The work cannot be determined unless the distance traveled is given.
- MC4. A boy and girl on ice skates are at rest and facing each other. The girl has a mass of 20 kg and the boy has a mass of 30 kg. The boy pushes the girl backward such that she achieves a speed of 3.0 m/s relative to the ice. As a result of the push, the speed of the boy is
- A) zero
 - B) 2.0 m/s
 - C) 3.0 m/s
 - D) 4.5 m/s
 - E) 9.0 m/s
- MC5. What is the force of gravity between the proton of mass $m_p = 1.67 \times 10^{-27}$ kg and the electron of mass $m_e = 9.11 \times 10^{-31}$ kg in a hydrogen atom, given that the average radius of the electron's orbit around the proton is 0.0529 nm?
- A) 1.9×10^{-57} N
 - B) 2.0×10^{-50} N
 - C) 3.6×10^{-47} N
 - D) 6.6×10^{-44} N
 - E) 5.4×10^{-37} N
- MC6. Any body moving with simple harmonic motion is being acted on by a force that is:
- A) Constant.
 - B) Proportional to a sine or cosine function of the displacement.
 - C) Proportional to the inverse square of the displacement.
 - D) Proportional to the displacement.
 - E) Proportional to the square of the displacement.

MC7. The energy of an oscillator decreases by 3% each cycle. The quality factor of this oscillator is approximately

- A) 0.19
- B) 33
- C) 67
- D) 105
- E) 209

MC8. The photograph to the right shows waves in a ripple tank generated by a point source at the center of wave pattern (ie. at the end of the dark line entering from the top). The point source is

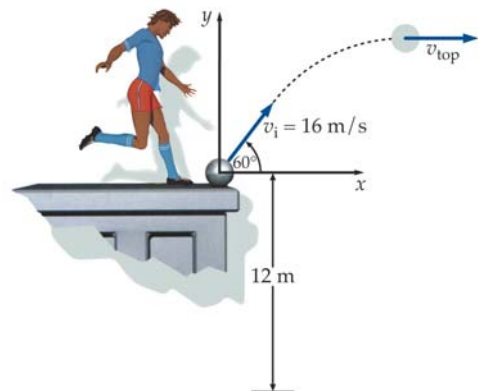
- A) moving from left to right.
- B) moving from right to left.
- C) moving from top to bottom.
- D) moving from bottom to top.
- E) not in motion.



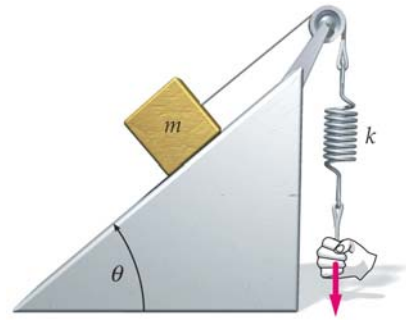
Problems (20 points each)

II. Standing near the edge of a roof of a 12 m high building, you kick a ball with an initial speed of $v_i = 16 \text{ m/s}$ at an angle 60° above the horizontal. Neglecting air resistance, find:

- a) How high the ball rises above the height of the building. (6 pts)
- b) The speed of the ball just before it hits the ground. (7 pts)
- c) The horizontal distance the ball travels before it hits the ground. (7 pts)



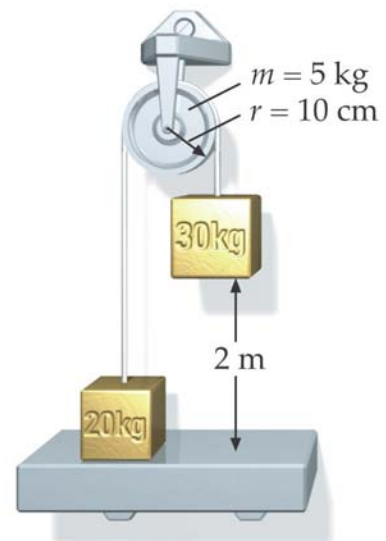
- III. A block of mass $m = 3 \text{ kg}$ rests on an inclined plane with $\theta = 20^\circ$. The coefficient of static friction between the block and the incline is $\mu_s = 0.4$. The mass is connected to spring with $k = 200 \text{ N/m}$ via a massless pulley and a string. A gradually increasing downwards force is applied to the spring. At the moment just before the block starts to move, find:



- The magnitude and direction of the static friction force between the block and the incline. (6 pts)
 - The elongation of the spring. (8 pts)
 - The potential energy of the spring, setting $U_s = 0$ when the spring is at its natural/unstretched length. (6 pts)
- IV. A 2 kg and a 5 kg cart can move on an airtrack without friction. Initially the 2 kg cart moves with a velocity of +8 m/s before colliding with the 5 kg cart which is initially at rest. After the collision, the 2 kg cart moves with a velocity of -1 m/s. Find:
- The velocity of the 5 kg cart after the collision. (7 pts)
 - The energy lost in the collision. (7 pts)
 - The coefficient of restitution. Is the collision elastic or inelastic? (6 pts)

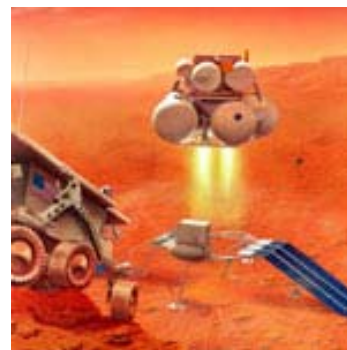
- V. The system in the figure on the right is released from rest, with the 30 kg block 2 m above the ledge. The pulley is a uniform disc with radius 10 cm and a mass of 5 kg. Assume the string does not slip on the pulley.

- Find the speed of the two blocks and the angular speed of the pulley just before the 30 kg block hits the ledge. (8 pts)
- Find the time it takes for the 30 kg block to reach the ledge. (6 pts)
- Find the tension in the string both on the 20 kg and 30 kg block side while the blocks are moving. (6 pts)



VI. NASA is currently planning so-called “Sample Return” missions to Mars ($M = 6.421 \times 10^{23}$ kg, $R = 3397$ km), which as the name suggests are aimed at bringing Martian samples back to Earth for scientific analysis.

- a) In order to determine the mass of the collected samples they are attached to a spring with a stiffness, $k = 0.2$ N/m, and then set into vibration. What is the mass of a sample if it oscillates with a frequency of 1.35 Hz? (5 pts)



For the launch of the samples from the surface of Mars into space two possibilities are considered. The first is a ballistic launch, ie. shooting a sample canister into space as a projectile.

- b) What is the escape velocity for Mars? (5 pts)

An alternative approach is with a rocket engine. Assume that the sample return vehicle including the engine and fuel has an initial mass of 20 kg and the engine has an exhaust speed of 2.3 km/s.

- c) What is the magnitude of the gravitational field at the surface of Mars? (5 pts)
d) What is the minimum burn rate of the rocket engine, which will allow the return vehicle to overcome the gravitational force on the surface of Mars? (5 pts)

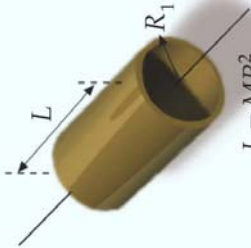
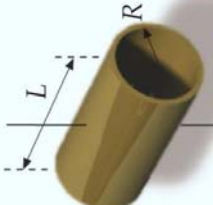
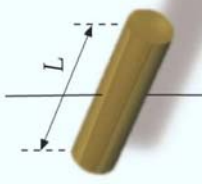
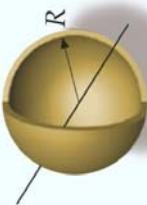
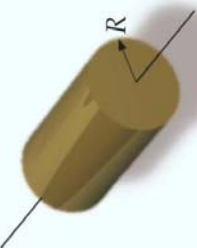
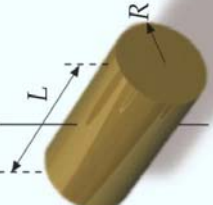
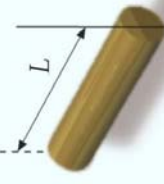
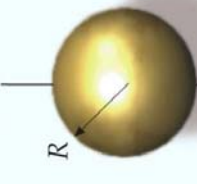
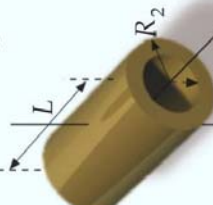
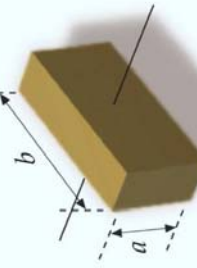
VII. A student drops a vibrating 440 Hz tuning fork down an elevator shaft of the Hesburgh library. Assume that the shaft is 60 m deep, and that the speed of sound is 340 m/s.

- a) How long does it take the tuning fork to reach the bottom of the shaft? (5 pts)
b) What is the velocity of the tuning fork at the instant when it reaches the bottom of the elevator shaft? (5 pts)
c) What is the frequency from the tuning fork heard by the student immediately before the sound of its impact with the bottom of the shaft? (5 pts)
d) How long after releasing the tuning fork does the student hear the sound of the impact? Please give this answer with three significant figures. (5 pts)



Table 9-1

Moments of Inertia of Uniform Bodies of Various Shapes

Thin cylindrical shell about axis	 $I = MR^2$	Thin cylindrical shell about diameter through center	 $I = \frac{1}{2}MR^2 + \frac{1}{12}ML^2$	Thin rod about perpendicular line through center	 $I = \frac{1}{12}ML^2$	Thin spherical shell about diameter	 $I = \frac{2}{3}MR^2$
Solid cylinder about axis	 $I = \frac{1}{2}MR^2$	Solid cylinder about diameter through center	 $I = \frac{1}{4}MR^2 + \frac{1}{12}ML^2$	Thin rod about perpendicular line through one end	 $I = \frac{1}{3}ML^2$	Solid sphere about diameter	 $I = \frac{2}{5}MR^2$
Hollow cylinder about axis	 $I = \frac{1}{2}M(R_1^2 + R_2^2)$	Hollow cylinder about diameter through center	 $I = \frac{1}{4}M(R_1^2 + R_2^2) + \frac{1}{12}ML^2$			Solid rectangular parallelepiped about axis through center perpendicular to face	 $I = \frac{1}{12}M(a^2 + b^2)$

A disk is a cylinder whose length L is negligible. By setting $L = 0$, the above formulas for cylinders hold for disks.