Do not turn the pages of the exam until you are instructed to do so.

Exam rules: You may use **only** a writing instrument while taking this test. You may **not** consult any calculators, computers, books, nor each other.

Problems 1 and 10 must be answered on the scantron form. Problems 11 and 12 must be answered in exam booklet 1. Problem 13 must be answered in exam booklet 2. The answers need to be well motivated and expressed in terms of the variables used in the problem. You will receive partial credit where appropriate, but only when we can read your solution. Answers that are not motivated will not receive any credit, even if correct.

At the end of the exam, you must hand in your exam, the scantron form, the blue exam booklets, and the equation sheet. All items must be clearly labeled with your name, your student ID number, and the day/time of your recitation. **If any of these items are missing, we will not grade your exam, and you will receive a score of 0 points.**

You are required to complete the following *Honor Pledge for Exams*. Copy and sign the pledge before starting your exam.

"I affirm that I will not give or receive any unauthorized help on this exam, and that all work will be my own."

Name: ______________________________

Signature: ______________________________

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$$\cos(30°)=\frac{1}{2}\sqrt{3} \quad \sin(30°)=\frac{1}{2} \quad \tan(30°)=\frac{1}{3}\sqrt{3}$$

$$\cos(45°)=\frac{1}{2}\sqrt{2} \quad \sin(45°)=\frac{1}{2}\sqrt{2} \quad \tan(45°)=1$$

$$\cos(60°)=\frac{1}{2} \quad \sin(60°)=\frac{1}{2}\sqrt{3} \quad \tan(60°)=\sqrt{3}$$

$$\cos\left(\frac{1}{2}\pi-\theta\right)=\sin(\theta) \quad \sin\left(\frac{1}{2}\pi-\theta\right)=\cos(\theta)$$

$$\cos(2\theta)=1-2\sin^2(\theta) \quad \sin(2\theta)=2\sin(\theta)\cos(\theta)$$

	Circle	Sphere
circumference	$2\pi r$	
(surface) area	πr^2	$4\pi r^2$
volume		$\frac{4}{3}\pi r^3$

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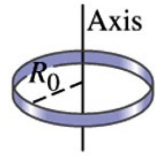
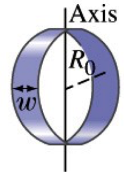
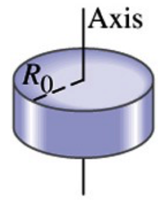
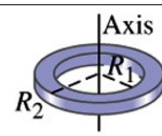
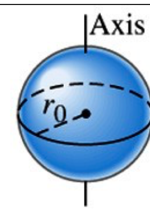
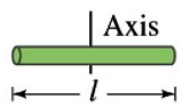
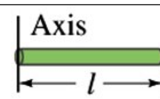
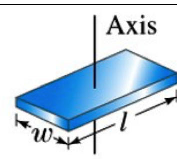
Moments of inertia of various objects of uniform composition.

(a)	Thin hoop of radius R_0	Through center		MR_0^2
(b)	Thin hoop of radius R_0 and width w	Through central diameter		$\frac{1}{2}MR_0^2 + \frac{1}{12}Mw^2$
(c)	Solid cylinder of radius R_0	Through center		$\frac{1}{2}MR_0^2$
(d)	Hollow cylinder of inner radius R_1 and outer radius R_2	Through center		$\frac{1}{2}M\,(R_1^2 + R_2^2)$
(e)	Uniform sphere of radius r_0	Through center		$\frac{2}{5}Mr_0^2$
(f)	Long uniform rod of length l	Through center		$\frac{1}{12}Ml^2$
(g)	Long uniform rod of length l	Through end		$\frac{1}{3}Ml^2$
(h)	Rectangular thin plate, of length l and width w	Through center		$\frac{1}{12}M(l^2 + w^2)$

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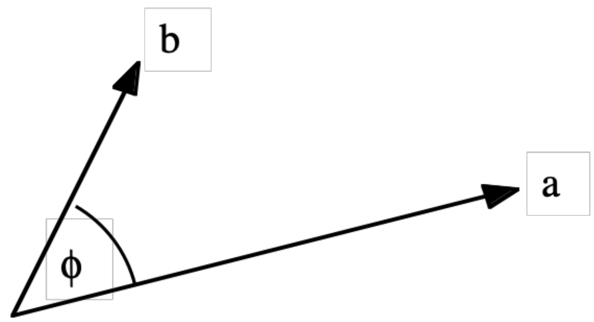
Properties of the scalar product



$$\vec{a} \bullet \vec{b} = |\vec{a}||\vec{b}|\cos\phi \tag{1}$$

$$\vec{a} \bullet \vec{a} = |\vec{a}|^2 \tag{2}$$

$$\left(\vec{a} + \vec{b}\right) \bullet \left(\vec{a} + \vec{b}\right) = \vec{a} \bullet \vec{a} + \vec{a} \bullet \vec{b} + \vec{b} \bullet \vec{a} + \vec{b} \bullet \vec{b} = |\vec{a}|^2 + |\vec{b}|^2 + 2\vec{a} \bullet \vec{b} \tag{3}$$

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Good Luck !

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Problem 1 (2.5 points) **Answer on Scantron form**

How old is the KLM?

Figure 1: The first KLM Boeing 787-10 was delivered on June 30, 2019, the year that the KLM celebrated its 100^{th} birthday.

1. 100
2. 101
3. 102
4. 103
5. 104
6. 105
7. 106
8. 107
9. 108
10. 109

Problem 2 (2.5 points) **Answer on Scantron form**

In the Rutherford experiment, what was surprising to the experimenters?

1. Sometimes the alpha particles passed right through the gold foil without being deflected.
2. Sometimes the alpha particles were deflected slightly when they passed through the gold foil.
3. Sometimes the alpha particles bounced back from the gold foil.

Problem 3 (2.5 points) **Answer on Scantron form**

The linear density of a long thin rod, of length L, decreases linearly from a value of ρ_0 at the left end to zero at the right end. How far from the left end is the rod's center-of-mass located?

1. $(1/5)\ L$
2. $(1/3)\ L$
3. $(2/3)\ L$
4. $(4/5)\ L$

Problem 4 (2.5 points) **Answer on Scantron form**

A solid disk and a ring roll down an incline. The ring is slower than the disk if

1. $m_{ring} = m_{disk}$, where m is the mass.
2. $r_{ring} = r_{disk}$, where r is the radius.
3. $m_{ring} = m_{disk}$ and $r_{ring} = r_{disk}$.
4. The ring is always slower, regardless of the relative values of m and r.

Problem 5 (2.5 points) **Answer on Scantron form**

A bicycle wheel with a heavy rim is mounted on a lightweight axle, and one end of the axle rests on top of a post, as shown in Fig. 2. The wheel is observed to precess in the horizontal plane.

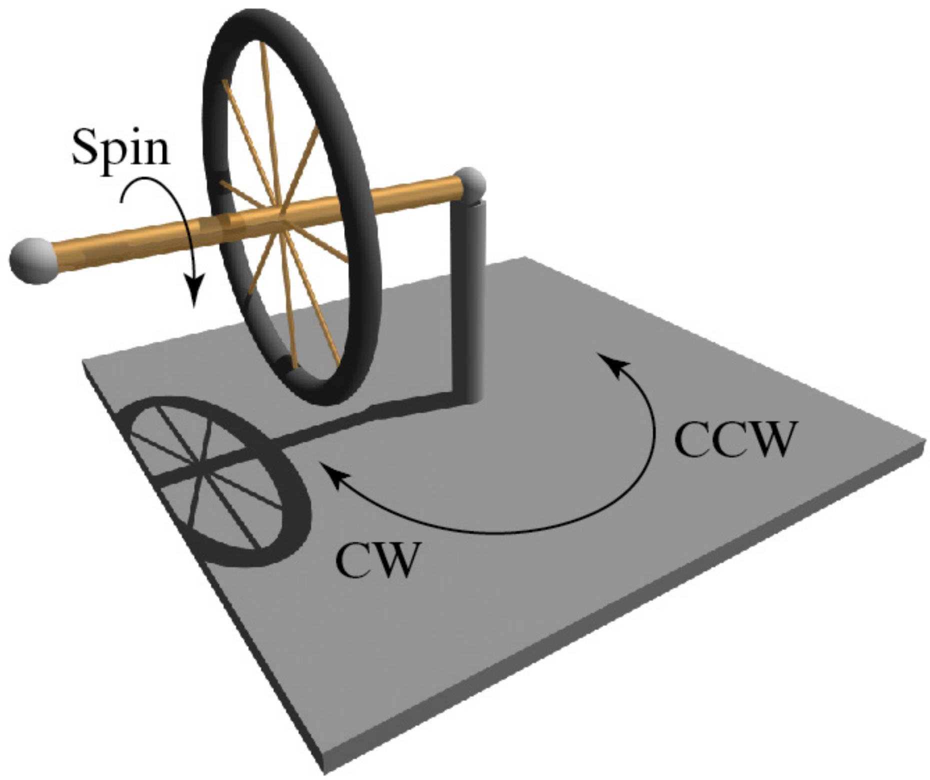

Figure 2: Precession of a bicycle wheel.

With the spin direction shown in the Fig. 2, in what direction will the wheel precess?

1. Counter clockwise (CCW).
2. Clockwise (CW).

Problem 6 (2.5 points) **Answer on Scantron form**

An emission spectrum for hydrogen is obtained by analyzing the light from hydrogen gas, heated to very high temperatures. An absorption spectrum is obtained by passing incandescent light through the cold gas (all atoms in the ground state).
Which of the following statements is correct?

1. The absorption spectrum will be identical to the emission spectrum.
2. The absorption spectrum will contain some, but not all, of the lines appearing in the emission spectrum.
3. The absorption spectrum will contain all the lines seen in the emission spectrum, plus additional lines.

Problem 7 (2.5 points) **Answer on Scantron form**

Assume a hypothetical object has just four quantum states with energies shown in Fig. 3. Suppose that the temperature is high enough that in a volume containing many such objects, at any instant some objects are found in all of these states. What are the energies of the photons that will be emitted from this volume?

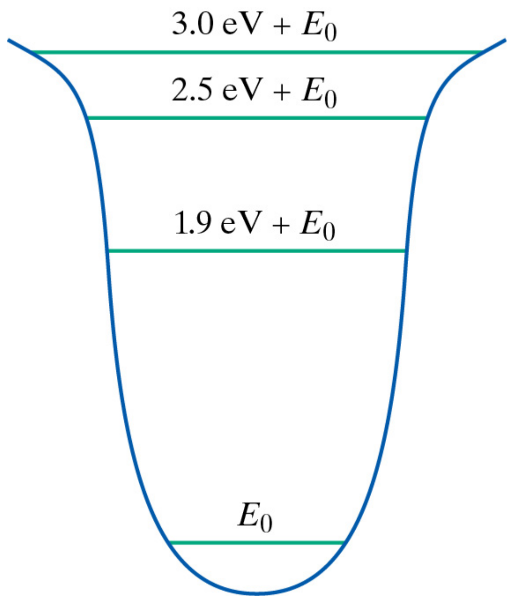

Figure 3: Energy levels of an object with four quantum states.

1. 1.9 eV, 2.5 eV, 3.0 eV.
2. 0.5 eV, 0.6 eV, 1.9 eV.
3. 3.0 eV.
4. 0.5 eV, 2.5 eV, 3.0 eV.
5. 1.1 eV, 1.9 eV, 3.0 eV.
6. 0.5 eV, 0.6 eV, 1.1 eV, 1.9 eV, 2.5 eV, 3.0 eV.
7. 0.6 eV, 1.9 eV, 2.5 eV.
8. 2.5 eV.
9. 1.9 eV.

Problem 8 (2.5 points) **Answer on Scantron form**

Which energy levels shown in Fig. 4 are appropriate for the following situations?

a) Vibrational states of a diatomic molecule such as O_2.

b) Idealized spring-mass oscillator.

c) Electronic and vibrational states of a diatomic molecule such as O_2.

d) Electronics states of a single atom such as hydrogen.

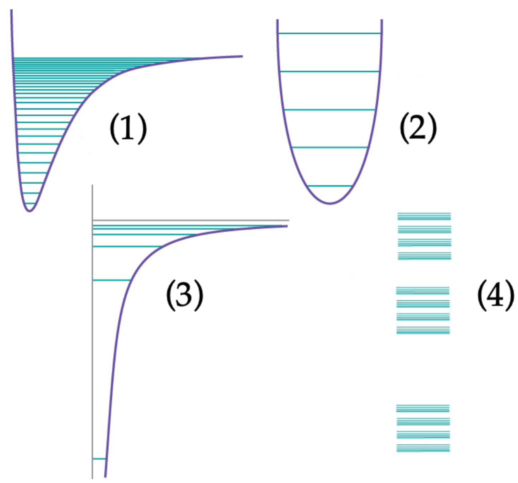

Figure 4: Energy levels.

1. (1=a), (2=b), (3=c), (4=d).
2. (1=a), (2=b), (3=d), (4=c).
3. (1=b), (2=a), (3=c), (4=d).
4. (1=b), (2=a), (3=d), (4=c).
5. (1=b), (2=d), (3=a), (4=c).
6. (1=c), (2=a), (3=b), (4=d).
7. (1=c), (2=a), (3=d), (4=b).
8. (1=d), (2=b), (3=c), (4=a).
9. (1=d), (2=b), (3=a), (4=c).
10. (1=d), (2=c), (3=b), (4=a).

Problem 9 (2.5 points) **Answer on Scantron form**

Consider the energy diagram shown in Fig. 5.

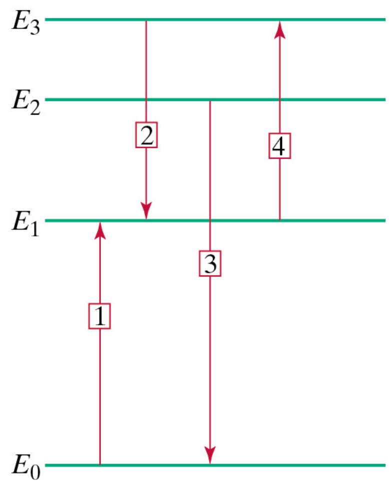

Figure 5: Atomic Transitions.

Match the description of the processes in the following list

a) Absorption of a photon whose energy is $E_1 - E_0$.

b) Absorption from an excited state (a rare event at low temperatures).

c) Emission of a photon whose energy is $E_3 - E_1$.

d) Emission of a photon whose energy is $E_2 - E_0$.

with the corresponding arrows in Fig. 5.

1. (1=a), (2=b), (3=c), (4=d).
2. (1=a), (2=c), (3=b), (4=d).
3. (1=a), (2=d), (3=c), (4=b).
4. (1=a), (2=c), (3=d), (4=b).
5. (1=b), (2=a), (3=c), (4=d).
6. (1=c), (2=a), (3=b), (4=d).
7. (1=c), (2=d), (3=a), (4=b).
8. (1=d), (2=c), (3=a), (4=b).
9. (1=d), (2=b), (3=c), (4=a).
10. (1=d), (2=a), (3=b), (4=c).

Problem 10 (2.5 points) **Answer on Scantron form**

Consider hydrogen gas maintained at a high temperature. Incandescent light is incident on the gas. Which of the transitions shown in Fig. 6 can be observed in this system?

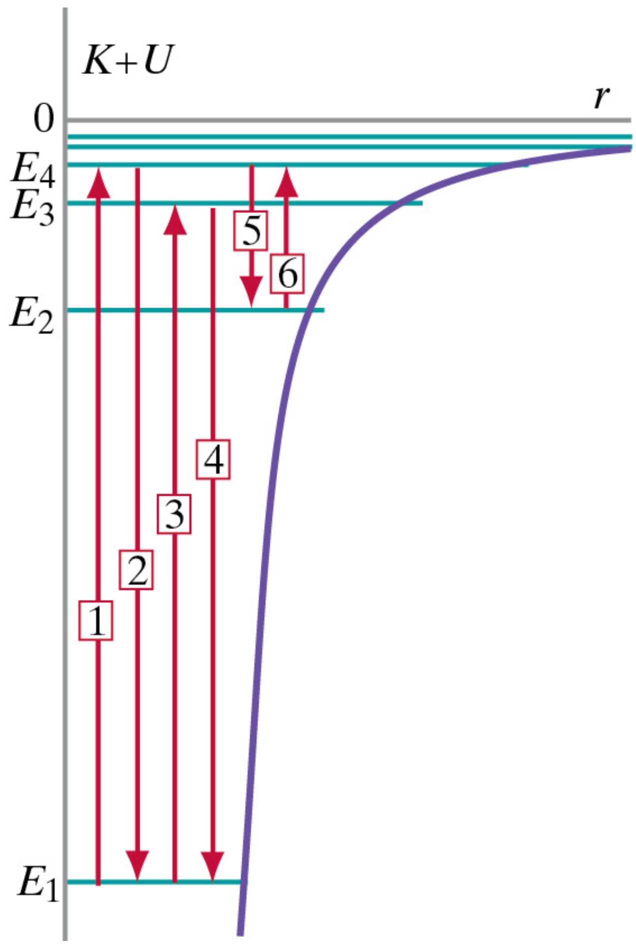

Figure 6: A chain of nuclear fission reactions.

1. Transitions 1, 3, and 6
2. Transitions 2, 4, and 5
3. Transition 6
4. Transitions 1 and 2
5. Transitions 1, 2, 3, and 4
6. Transitions 5 and 6
7. Transitions 1, 2, 3, 4, 5 and 6
8. Transition 5

Problem 11 (25 points) **Answer in booklet 1**

A chain of metal links with a total mass M is coiled up in a tight ball on a low-friction table, as shown in Fig. 7. You pull on a link at one end of the chain with a constant force F. Eventually the chain straightens out to its full length L and you keep pulling until you have pulled your end of the chain a total distance d.

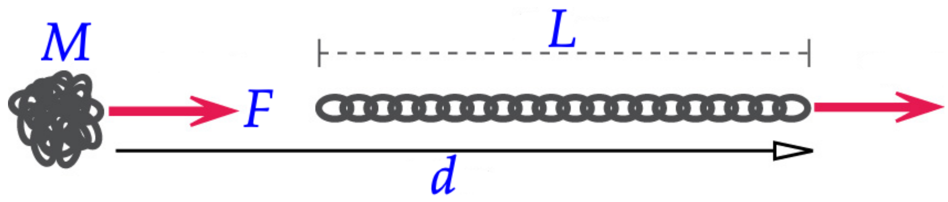

Figure 7: Unrolling a chain.

a) (**10 points**) What is the speed of the chain at this instant?

b) (**5 points**) What is the change in the kinetic energy of the chain?

c) (**10 points**) In straightening out, the links of the chain bang against each other, and their temperature rises. Assume that this process is so fast that there is insufficient time for a significant transfer of energy from the chain to the table due to the temperature difference and ignore the small amount of energy radiated way as sound produces in the collisions among the links. Calculate the increase in the internal energy of the chain.

Your answers needs to be well motivated and expressed in terms of the variables provided.

Problem 12 (25 points) **Answer in booklet 1**

A thin metal rod of mass M and length L is at rest in outer space. A tiny meteorite with mass m travelling with a speed v_i strikes the rod a distance d from the center and bounces off with speed v_f, as shown in Fig. 8. The initial and final angles of the meteorite, θ_i and θ_f, are known.

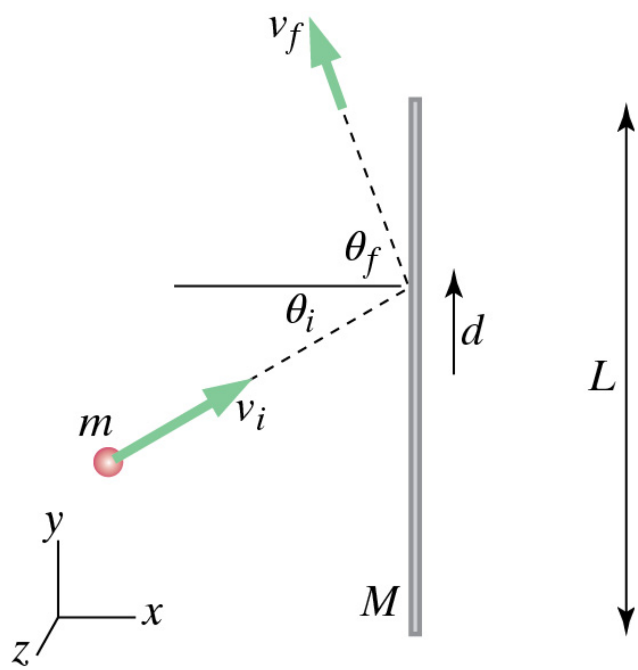

Figure 8: A meteorite striking a rod.

a) (**10 points**) What is the velocity of the center of the rod after the collision? **Note: you need to specify the magnitude and the direction.**

b) (**10 points**) What is the angular velocity of the rod after the collision? **Note: you need to specify the magnitude and the direction.**

c) (**5 points**) What is the change in the internal energy of the objects?

Your answers needs to be well motivated and expressed in terms of the variables provided.

Problem 13 (25 points) **Answer in booklet 2**

Consider a two-dimensional elastic collision in which a ball of mass m and linear momentum p_1 collides with s stationary ball of mass m, as shown in Fig. 9. We will use a coordinate system in which the moving ball in Fig. 9 is moving along the x axis.

Figure 9: An elastic collisions with a stationary target shown in the laboratory frame, in which the target is at rest before the collision.

a) (**5 points**) What is the center-of-mass velocity of the system before the collision? **Note: you need to specify both magnitude and direction.**

b) (**5 points**) We will describe this collision in a reference frame where the center-of-mass of the system is at rest. In this reference frame, what is the linear momentum of both balls before the collision? **Note: you need to specify both magnitude and direction.**

c) (**5 points**) After the collision, the target ball moves in the center-of-mass frame at an angle θ with respect to the x axis. What is its linear momentum in the center-of-mass frame.

d) (**5 points**) What is the direction of motion of the target ball after the collision in the laboratory frame? You need to specify the angle between the direction of motion of the target ball in the laboratory frame and the x axis.

e) (**5 points**) What is the kinetic energy of the target ball after the collision in the laboratory frame?

Your answers needs to be well motivated and expressed in terms of the variables provided.

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Figure 10: The real world series being played in Mexico between November 9, 2024 and November 24, 2024.