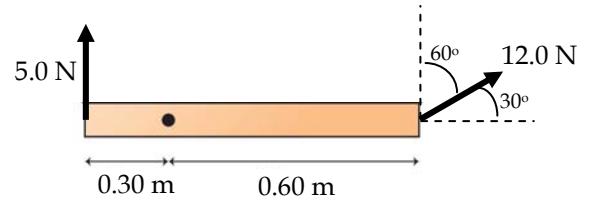


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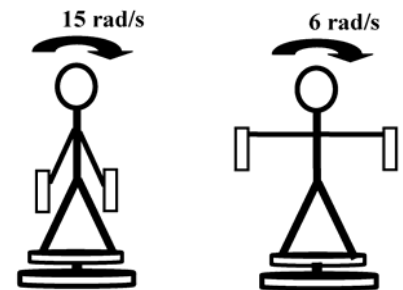
1) The figure is a bird's eye view and the only forces exerting torque are shown. The bar is free to pivot about the axis indicated by the dot. The moment of inertia of the bar about the axis indicated by the dot is $0.30 \text{ kg} \cdot \text{m}^2$.



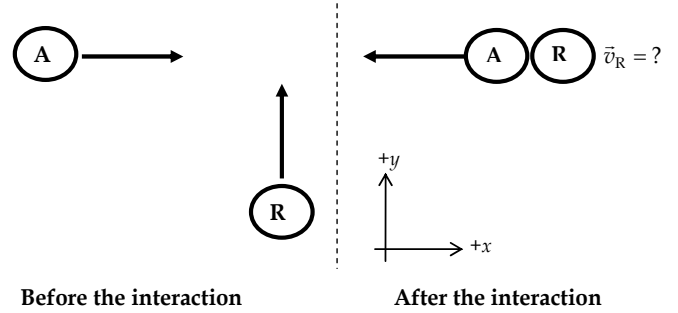
a) Determine the magnitude of the net torque on the bar.

b) Determine the magnitude of the angular acceleration of the bar.

2) Your friend stands on a horizontal platform that is free to rotate without friction. She holds a calculus textbook in each hand, with her arms resting along her sides. The combined moment of inertia of the two books, platform, and woman is $10 \text{ kg} \cdot \text{m}^2$. You spin her so that her angular speed is 15 rad/s . She then holds her arms out away from her body, and her angular speed decreases to 6 rad/s . Determine the combined moment of inertia after she lifts her arms away from her body.



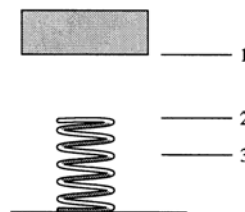
3) Astronauts Arlo and Rebecca are on a collision course in outer space. Arlo (mass 45 kg) is moving in the $+x$ direction at 1.0 m/s. Rebecca (mass 60 kg) is moving in the $+y$ direction at 2.0 m/s. On colliding, the astronauts push off of each other in such a way that Arlo now moves in the $-x$ direction, but still at 1.0 m/s. After the interaction, Rebecca is now moving with some unknown velocity \vec{v}_R .



Determine:

- v_y , the y -component of Rebecca's speed after the interaction;
- v_x , the x -component of Rebecca's speed after the interaction;
- the magnitude of Rebecca's speed after the interaction; and
- Rebecca's direction after the interaction, reported as an angle and shown on a sketch.

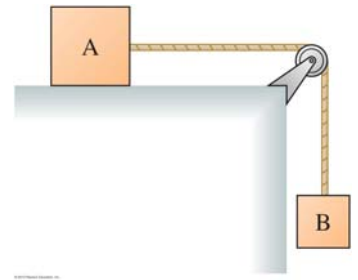
4) A heavy object is released from rest at position 1 above a spring. It falls and contacts the spring at position 2. The spring achieves maximum compression at point 3. See the figure. Fill in the table to indicate whether each of the quantities are **+**, **-**, or **0** during the intervals $1 \rightarrow 2$, $2 \rightarrow 3$, and $1 \rightarrow 3$.



	1→2	2→3	1→3
ΔK			
ΔU_g			
ΔU_s			

5) The figure shows box A (mass 6 kg) and box B (mass 2 kg) connected by a light-weight rope over an ideal, massless pulley. The boxes are released from rest.

a) After box B has fallen 1.225 m, what is the speed of box A and box B? Neglect friction between box A and the table.



b) If the masses were switched so that box A were 2 kg and box B were 6 kg and released from rest, what can you say about A and B's speed after B had fallen 1.225 m? Neglect friction between box B and the table. (circle one, and **note the follow-up question**)

It would be larger

It would be the same

It would be smaller

Not enough info.

Briefly explain your reasoning for your choice.

c) Consider the original scenario. You make some measurements, and find that friction can't be neglected. When box B has fallen from rest a distance of 1.225 m, friction between box A and the table has transformed 8.01 J into non-mechanical forms (likely thermal energy). Determine the speed of box A and B after B has fallen from rest a distance of 1.225 m.

6a) In a scene from *Fast and Furious X*, observers on the ground observe the Rock in his car to be moving at a constant speed of 60 mph in a straight line, while Vin Diesel in his car is moving at a constant speed of 90 mph in the same direction. According to the Rock in his car, how fast is Vin Diesel going?

6b) In a scene from *Fast and Furious XXX*, observers on the ground observe the Rock in his rocket-car to be moving at a constant speed of $0.60c$ in a straight line, while Vin Diesel in his rocket-car is moving at a constant speed of $0.90c$ in the same direction. According to the Rock in his rocket-car, how fast is Vin Diesel going?

6c) You are standing on a train moving at constant velocity of $0.5c$ to the right with respect to the ground. You shine a pulse of light to the left. The speed of light is $1.0c$ in your reference frame. What does a ground-based observer measure for the speed and direction of the light pulse? (circle one)

$0.5c$
(to the left) **$1.0c$**
(to the left) **$1.5c$**
(to the left) **$0.5c$**
(to the right) **$1.0c$**
(to the right) **$1.5c$**
(to the right)

7) A cosmic ray particle moving down toward Earth at constant speed decays 4.0 ms after it was produced as measured in the frame in which the particle is at rest. According to observers in the Earth frame, the particle traveled a distance of $3.0 \text{ lt} \cdot \text{ms}$ between its production and its decay. How fast was the particle moving?

8) Amy is sitting in the very front of a train, while Penny is sitting in the very back of the train. According to Amy and Penny, the train is $1.875 \text{ lt} \cdot \text{ms}$ long. Sheldon is sitting on the tracks next to the train when it passes him by. Sheldon measures that the time between Amy passing him by and Penny passing him by is 2.5 ms. Amy and Penny measures that the time between Sheldon passing by them is 3.125 ms.

a) Whose measured time is the proper time? (circle all that apply, and **note the follow-up question**)

Amy

Penny

Sheldon

None of them

Briefly explain your reasoning for your choice.

b) Who measures the rest length of the train? (circle all that apply, and **note the follow-up question**)

Amy

Penny

Sheldon

None of them

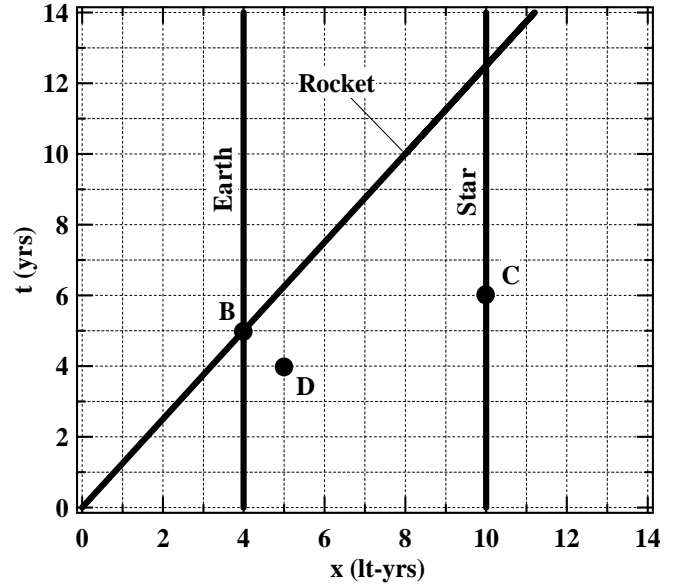
Briefly explain your reasoning for your choice.

c) How fast is the train moving, according to Sheldon?

d) How long is the train, according to Sheldon?

9) The spacetime diagram shows the world lines of the Earth, a Star, and a Rocket, as well as several labeled events.

a) Determine the speed of the Rocket, as measured by Earth observers.



b) Order events B, C, and D from earliest to latest in the Rocket's reference frame. Indicate any ties with an = sign.

Earliest Latest

c) Which of the following could be true? (circle all that apply)

- B could cause D B could cause C C could cause B C could cause D D could cause B D could cause C

d) As measured by observers on a comet moving at constant speed with respect to the Earth (in the same direction as the Rocket), events C and D happen at the same time. Determine the speed of this comet with respect to the Earth.

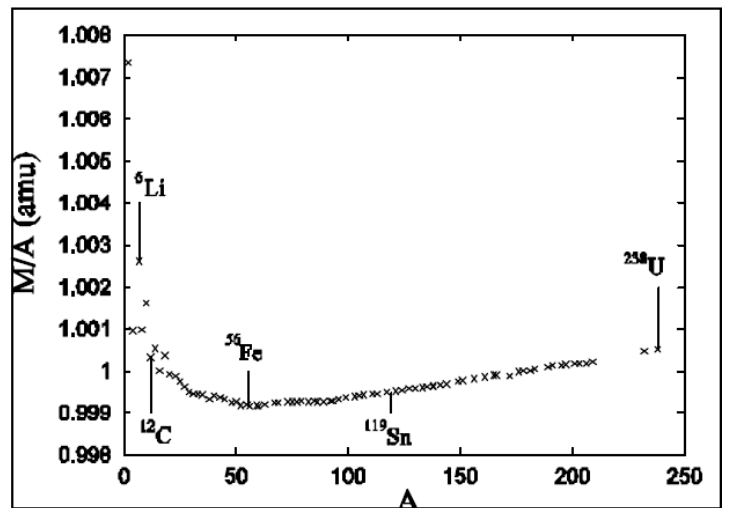
10) The graph shows the average mass per nucleon (M/A) for various nucleon numbers (A).

a) Two lithium nuclei (${}^6\text{Li}$) combine to form a single carbon nucleus (${}^{12}\text{C}$). What happens in this reaction? (circle one)

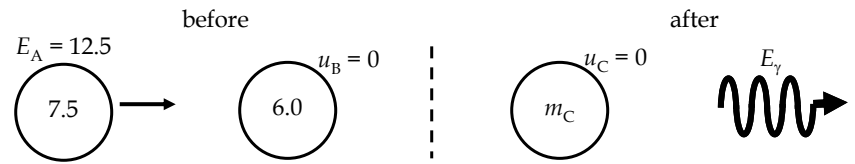
- | | |
|--|---|
| mass is converted to kinetic energy | no energy conversions occur in this reaction |
| kinetic energy is converted to mass | not enough information to choose |

b) Two tin nuclei (${}^{119}\text{Sn}$) combine to form a single uranium nucleus (${}^{238}\text{U}$). What happens in this reaction? (circle one)

- | | |
|--|---|
| mass is converted to kinetic energy | no energy conversions occur in this reaction |
| kinetic energy is converted to mass | not enough information to choose |



11) Particle A ($m = 7.5 \text{ GeV}/c^2$, $E = 12.5 \text{ GeV}$) moves to the right and collides with stationary particle B ($m = 6.0 \text{ GeV}/c^2$.) The result is stationary particle C of unknown mass m_C and a photon γ of unknown energy E_γ .



Determine, in any order you wish, particle A's:

a) momentum	b) speed	c) kinetic energy
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d) Which quantities are conserved in this reaction? (circle all that apply)

mass

momentum

energy

kinetic energy

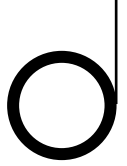
none of these

e) Determine p_γ and E_γ , the momentum and energy of the photon.

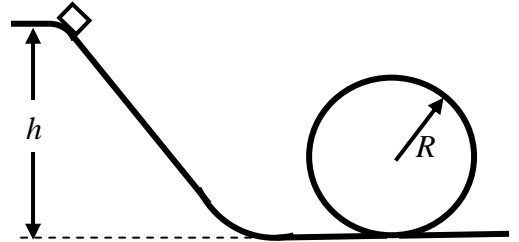
f) Determine E_C and m_C , the energy and mass of particle C.

****COMPLETE ANY OF THE REMAINING PROBLEMS IF YOU HAVE TIME. THESE PROBLEMS MAY BE MORE CHALLENGING THAN MANY OF THE PREVIOUS PROBLEMS ON THIS EXAM. ANSWER ON SEPARATE PAGES AS NEEDED.****

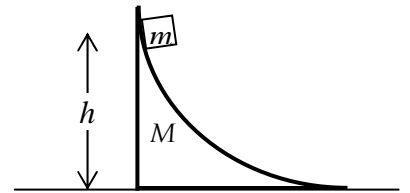
12) A light-weight string is wrapped around the outer edge of a hollow cylinder (mass M , radius R , moment of inertia MR^2). You hold the end of the string stationary and the cylinder unwinds without the string slipping. Determine the acceleration of the cylinder while unwinding, in terms of g .



13) A block of mass m starts from rest at height h and slides down a frictionless ramp. At the end of the ramp, the block slides into a (frictionless) loop of radius R . If the block starts too low, it will not make it all the way around the loop. What is the minimum height h (in terms of R) so that the block makes it all the way around the circular loop?



14) A block of mass m begins at rest a height h above the ground on a curved ramp of mass M . There is no friction between the block and the ramp. There is also no friction between the ramp and the ground, so that as the block moves along the ramp, the ramp also moves along the ground. Eventually the block reaches the ground moving to the right while the ramp moves to the left. Determine the speed of the ramp and the speed of the block after they have separated, in terms of any of m , M , g , and h .



15) An observer on a planet measures a cosmic ray particle to be moving with momentum $8 \text{ MeV}/c$ and energy 10 MeV . A second observer in a rocketship moving in the same direction as the particle measures this particle to have energy 6.5 MeV . What is the speed of the rocketship with respect to the planet?