Mechanics 2, example exam questions, NWI-MOL160

Prof. Gerrit C. Groenenboom, 14-Oct-2026

You can bring a double sided sheet of printed or handwritten formulas to the exam. On the website is an example of such a list.

- Put your name, student number, and date on every page.
- Number your pages x out of y.
- You may use a handwritten or printed doubled sided formula sheet with notes (no need to turn it in after the exam).
- Use of a calculator is also allowed.
- Always explain how you got your answer and make a drawing of the problem when applicable.
- When some effect, e.g., friction, is not mentioned in a question, it can be neglected.
- The exam consists of 4 questions with a total of 12 subquestions. All (sub)questions weigh equally towards the final grade.
- Moments of inertia and physical constants are given on the last page.
- If you registered for extra time you can use that.

Question 1: Dropping a spinning wheel

A bicycle wheel with a diameter of 70 cm is held by an axle and it is rotating in a vertical plane with an angular velocity of $\omega_i = 20$ rad/s. The wheel is held just above the road. When the wheel is dropped, it rolls away. Initially, the tire is slipping on the road, but after a little while it is rolling without slipping and the center of the wheel is moving horizontally with a velocity v_f. The mass of the wheel is $m = 2$ kg. The goal is to find the velocity v_f.

1a. [**5 points**] Being lazy, you first ask your favorite AI, and the answer you get starts like this:

> *"The wheel has a diameter of 70* cm *and its angular velocity is* $\omega_i = 20$ rad/s*, so the velocity is ..."*

What v_f would you get when you follow this logic?

1b. [**10 points**] Wondering whether this answer is correct, you do a calculation in which you assume that mechanical energy is conserved. You also assume the mass is at the outer edge of the wheel. What velocity v_f do you get with this approach?

1c. [**10 points**] Still not sure you've got the right answer, you decide to try using conservation of angular momentum instead. What v_f do you get?

1d. [**10 points**] For each of these three approaches, explain whether it is wrong or right. Also, explain why the result of **1c** is smaller, equal, or larger than the result of **1b**.

Question 2: Three collision experiments



In a physics experiment two carts move on an air track of length $L = 3$ m. The carts are launched simultaneously from both ends of the track with launchers that give each cart a kinetic energy of 0.1 J. The mass of Cart A is $m_1 = 200$ g and the mass of Cart B is $m_2 = 400$ g. The air track gives frictionless motion, and is assumed to be mounted perfectly horizontally.

2a. [**8 points**] What is the velocity of the center-of-mass of the two carts after they collide elastically?

In a **second experiment** carts of equal weight, $m_1 = m_2 = 200$ g are given a velcro bumper so they stick to each other after the collision. The carts are launched with the same launchers that give them 0.1 J kinetic energy each. The velocity of the carts is measured 2 seconds after they were launched, which is after the collision occurred, but before the carts hit the end caps. It is observed that this velocity (v_f) is small, but not exactly zero. The reason could be that the airtrack is not mounted perfectly horizontally.

2b. [**8 points**] Assuming that initially Cart A is 3 cm higher than Cart B and they start $L = 3$ m apart, compute the velocity that you expect to be measured two seconds after the carts are launched.

An other explanation could be that the launchers do not actually give the carts the exact same initial velocity. To test this idea the launchers are swapped and it is observed that after the collision the carts still get the same speed as in the previous experiment, but now they move in the opposite direction. It is concluded that the track is horizontal, but the problem is that the launchers are not identical.

2c. [**8 points**] If launcher 2 gives Cart B 0.1 J, but launchers 1 gives Cart A 0.11 J, how fast would the carts move after they collide and stick together? (The masses are still 200g)

Question 3: Putting a satellite in orbit

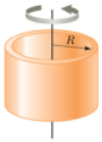
This question is about the energy required to put a satellite in orbit, but we will consider three somewhat different cases. In this question only consider the satellite, not the rocket that is required to actually do the work. The mass of the satellite is $m = 10$ kg. The Earth is approximated as a perfect sphere with a rotation period of 24 hours.

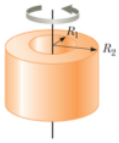
3a. [**8 points**] How much energy does it take to vertically lift the satellite at the North Pole to a fixed point 200 km above the surface? *(Hint: At the North Pole, the rotation of the Earth can be ignored.)*

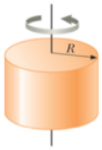
3b. [**10 points**] How much energy does it take to not only bring the satellite to a height of 200 km above the surface starting at the North Pole, but to put it in a *polar orbit* that is 200 km above the Earth surface? *Note: in a polar orbit the satellite flies over the North and South Pole.*

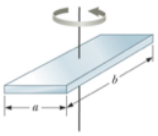
3c. [**7 points**] How much energy does it take to put this satellite in an orbit 200 km above the equator, starting somewhere at the equator? If you cannot calculate this, explain why it takes less, an equal amount, or more energy when starting from the equator.

Moments of inertia for selected objects and rotation axes

$I_{\text{CM}} = MR^2$ 

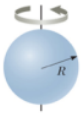
 $I_{\text{CM}} = \frac{1}{2}M(R_1^2 + R_2^2)$

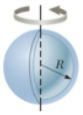
$I_{\text{CM}} = \frac{1}{2}MR^2$ 

 $I_{\text{CM}} = \frac{1}{12}M(a^2 + b^2)$

$I_{\text{CM}} = \frac{1}{12}ML^2$ 

 $I_{\text{CM}} = \frac{1}{3}ML^2$

$I_{\text{CM}} = \frac{2}{5}MR^2$ 

 $I_{\text{CM}} = \frac{2}{3}MR^2$

Selected constants and values

Gravitational constant:	$G = 6.674 \times 10^{-11}\ \text{N}\,\text{m}^2/\text{kg}^2$
Sun mass:	$M_S = 1.989 \times 10^{30}\ \text{kg}$
Sun radius:	$R_S = 6.96 \times 10^{8}\ \text{m}$
Earth mass:	$M_E = 5.97 \times 10^{24}\ \text{kg}$
Earth radius:	$R_E = 6.37 \times 10^{6}\ \text{m}$
Moon mass:	$M_M = 7.35 \times 10^{22}\ \text{kg}$
Moon radius:	$R_M = 1.74 \times 10^{6}\ \text{m}$
Earth distance from Sun:	$d_E = 1.496 \times 10^{11}\ \text{m} = 1\ \text{AU}$ (astronomical unit)
Density of air:	$\rho_{\text{air}} = 1.29\ \text{kg}/\text{m}^3$
Density of water:	$\rho_{\text{water}} = 1.00 \times 10^{3}\ \text{kg}/\text{m}^3$
Surface tension water/air:	$\gamma = 7.2 \times 10^{-2}\ \text{N}/\text{m}$