Høsten 2019

FYS100 Fysikk: Hand-in XI

To be handed in at the latest **Friday 1st November 2019, at 23.59**.
You **must** hand it in by scanning your handwritten solution or compiling your electronic documents into **a single .pdf** file, and uploading it to Canvas in "Week Eleven Exercises". Bad mobile phone pictures are not acceptable (there are apps that work OK), nor are any other file formats than a single .pdf.

You **must**:

- Put your name and student number on each page.
- Make sketches for all problems, where it makes sense.
- Write in a readable, well-structured way.

Pass is 40% correct (including partial credit). There is no grade. There is **no option** to correct and resubmit.

Good luck!

Image credit: David Gubler

Give six marks for problem 1, two for each part. Give six marks for problem 2, one for a diagram, one for each linear force equation and the torque equation, one for realising that the frictional force has a maximum of μN (and not just assuming it is always this) and one for completing the proof. Give three marks for problem 3, one for using conservation of angular momentum, one for a correct algebraic expression and one for a correct numerical answer and direction of rotation. 15 marks in total, six needed for a pass.

Problem 1: Forces, torque and power

The IORE electric locomotives that pull the iron-ore trains on the Ofotbanen/Malmbanan between Kiruna and Narvik are some of the most powerful in the world. The locomotives, working in pairs, weigh 180 tonnes each. They can pull up to 68 iron-ore wagons weighing 120 tonnes each. The wagons are coupled together using SA-3 couplers that were designed in the Soviet Union in the 1930s.

a) The wheels on the locomotives have a maximum diameter of 1250mm when new and a minimum diameter of 1150mm when worn. If each of the electric motors on the drive axles (of which there are 6 per locomotive) can generate a maximum torque of 115kNm, what is the maximum tensile force that the wagon couplers must withstand when the train is starting from rest?

Solution: For the given torque, the maximum force is generated when the wheels are worn and the force generated is 100kN per axle. Since there are 12 axles, the total force is 1200kN. This force must move the locomotives (2*180=360) tonnes and the wagons (68*120=8160) tonnes. So the force on the wagons is 1200*8160/(360+8160)=1150kN (3 sig. fig.) The first coupler between the locomotives and the first wagon is the one that must withstand this maximum tensile force and is most likely to break.

b) If each electric motor has a constant power output of 920kW, what total force do they apply when the train is travelling on horizontal track at a speed of 60km/h?

Solution: Each motor provides 920kW and there are 12 of them, so the total power output is 12*920=11040kW. Since power is force times velocity, the force is 11040/(60*1000/3600)=662kN. Note that this is less than the answer in part (a). Some (most?) students might just take the answer from part (a) here, but this is not strictly correct as the torque provided by the motors falls off as the speed is increased. Give partial marks if they do this.

c) If we assume that the force in part (b) is purely a resistive force due to the air and scales as v^2, with what constant speed in km/h can the train climb an incline of 10‰(which is the steepest incline on the line coming from Sweden)?

Solution: Going uphill the motors need to overcome not just the air resistance, but also the component of gravity along the slope. The slope has $\tan\theta = 0.01$. The air resistance force is given by $662 * v^2/(60 * 1000/3600)^2$. The weigh force is (360+8160)*1000*9.83*sin θ. Then we obtain an equation P = Fv = $662*1000*v^3/(60*1000/3600)^2+(360+8160)*1000*9.83*\sin\theta v = 11040*1000$.

This is now a cubic equation and some of the students might not know what to do with it. They can solve it using a computer, or by plotting a graph, or by Newton-Raphson (if they know what that is) or by looking up the formula for a cubic. Note they don't need the exact answer as they will only need two or three significant figures. I get a velocity of 36.6 km/h. If one ignores the air resistance (some students may do this) I get 47.5 km/h.

Problem 2: Krefter og friksjon

En stige med lengde l og masse m_s står oppetter en friksjonsfri vegg. Den nedre enden av stigen står på en horisontal flate der friksjonskoeffisienten er μ. Stigen danner vinkelen α med underlaget, og stigens massesenter ligger midt på stigen. Vis at en person med masse m_p kan stå hvor som helst på stigen når

$$\mu = \frac{m_p + \frac{m_s}{2}}{m_p + m_s} \frac{1}{\tan\alpha}.$$

Solution: Resolve the forces horizontally and vertically taking normal and friction forces at the top of the ladder f_1 and N_1 and likewise f_2 and N_2 at the bottom.

$$N_2 + f_1 - m_s g - m_p g = 0$$
$$N_1 - f_2 = 0$$

Resolve the torques around the point at the bottom of the ladder and allow the person to stand a distance X from the bottom.

$$\frac{l}{2} m_s g \cos\alpha + X m_p g \cos\alpha - l N_1 \sin\alpha - l f_1 \cos\alpha = 0$$

Use the linear force equations to eliminate N_1 and f_1, divide through by $\cos\theta$ and rearrange for X.

$$X m_p g = l \left[f_2 \tan\alpha + \frac{m_s g}{2} + m_p g - N_2 \right]$$

For any value of X, both N_2 and f_2 must adjust their values for this equation to hold, where f_2 is limited to be $f_2 \le \mu N_2$. The max value of f_2 ocurs when $X = l$ (person stands at the top of the ladder) for which

$$f_2 \tan\alpha = N_2 - \frac{m_s g}{2} \le \mu N_2 \tan\alpha$$

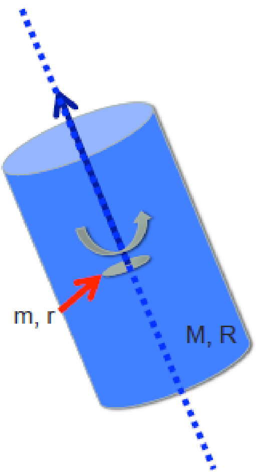
Note that f_1 helps to stop the ladder from slipping. Allowing $f_1 = 0$ (if the wall was greased or made of ice) gives $N_2 = m_s g + m_p g$ from the vertical force equation. Substituting this in gives

$$\mu \ge \frac{m_p + \frac{m_s}{2}}{m_p + m_s} \frac{1}{\tan\alpha}.$$

The person can stand anywhere on the ladder for all values of μ greater than or equal to this.

Problem 3: Conservation of angular momentum (Konte-exam 2016)

Solution: Use conservation of angular momentum. The total angular momentum of spaceship plus CD must remain zero. The spaceship must rotate in the opposite direction to the CD with an angular speed of $\omega_s = \frac{mr^2}{2MR^2}\omega_{CD} = 6.79 \times 10 * -7\mathrm{s}^{-1}$.



A spaceship is travelling with engines off far away from everything. Inside, a CD-player suddenly goes on, spinning the CD with 4 revolutions per second. The spaceship (not including the CD) can be thought of as a hollow cylinder ($I = MR^2$) of radius $R = 1.00$ m and mass 1000 kg. The CD is a uniform disc ($I = mr^2/2$) of mass $m = 15.0$ g and radius $r = 6.00$ cm. The axis of the spinning CD coincides with the symmetry-axis of the cylinder, and it is spinning according to the right-hand-rule around this axis.

a) In what direction and with what angular speed does the spaceship start rotating? The spaceship is assumed to not spin initially. Hint: Yes, it is very small.

Provide an algebraic expression, a sketch, and a number.