# Physics 1A for NB

Retake exam (2nd half of this course)

May 4, 2016, 9:00-12:00h

The exam consists of five problems. Make each problem on a separate answer sheet, and hand the sheets in separately. Always show your work, and give full calculations / derivations / arguments.

## 1 Testing your knowledge (8 points)

NB: When applicable, always explain your answers!

(a) When is the total angular momentum of a system conserved?

(b) Give both the thermodynamic and informational definitions of entropy.

(c) Give the magnitude and direction of the rotation vector of the Earth for the rotation that causes the day-night pattern (i.e. not the slower rotation of Earth around the sun).

(d) Sketch the phase diagram of methane. Indicate all phases and relevant points. Don't forget to label your axes.

## 2 Moving on a merry-go-round - 10 points

A cockroach of mass $m$ lies on the rim (i.e., the edge) of a circular disk with a uniform mass density. The disk has mass $10m$. The disk rotates freely about its center like a merry-go-round. Initially the cockroach and the disk rotate together with an angular velocity of 0.25 rad / s. Then the cockroach walks halfway to the center of the disk.

(a) What then is the angular velocity of the cockroach-disk system?

(b) Let $K$ be the new kinetic energy (after the cockroach has moved into a point halfway to the center of the disk). Let $K_O$ be the initial kinetic energy (when the cockroach was standing on the rim of the disk). Calculate $\frac{K}{K_O}$.

(c) What accounts for the change in the kinetic energy (i.e. why are $K$ and $K_O$ different?)

## 3 Rotating objects - 10 points

Two children with mass $m_1 = 10$ kg and $m_2 = 10$ kg sit on a simple merry-go-round that can be described as a solid disk of 100 kg with a radius of 2.0 m. The merry-go-round is free to rotate about its center, and initially does so with a frequency $\omega_0$ of 5.0 revolutions per minute. A third child with mass $m_3 = 10$ kg runs towards the merry-go-round with a speed $v_0$ of 1.0 m/s, and under an angle of 30° with the tangent to the merry-go-round (see figure 2a). When arriving at the merry-go-round, the third child jumps on it, and afterwards spins around with the other two.

(a) Find the rotational velocity of the merry-go-round after the third child jumped on it.

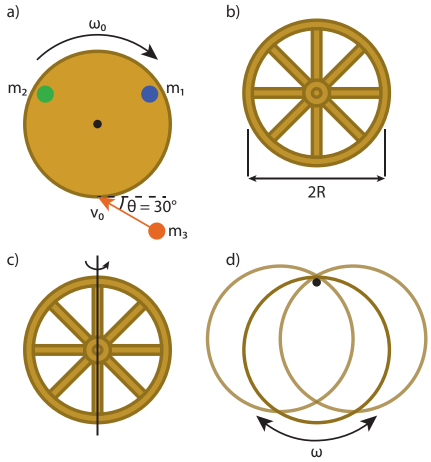


Figure 1: Four rotating systems. a) Three children on a merry-go-round. b) and c) Wagon wheel. d) Hula hoop on a peg.

A wagon wheel is constructed as shown in figure 2b. The radius of the wheel is $R$. Each of the spokes that lie along the diameter has a mass $m$, and the rim has mass $M$ (you may assume the thickness of the rim and spokes are negligible compared to the radius $R$).

(b) What is the moment of inertia of the wheel about an axis through the center, perpendicular to the plane of the wheel?

(c) For the same wheel as in (b), what is the moment of inertia for an axis through the center and two of the spokes, in the plane of the wheel (figure 2c)?

(d) A hula hoop of mass $M$ and radius $R$ hangs from a peg. Find the period of the hoop as it gently rocks back and forth on the peg (figure 2d).

## 4 Thermal processes 1 - 10 points

In this problem, you can use the following numbers for water, if necessary: Melting point = 237 K, heat of fusion = 334 kJ/kg, boiling point = 373K, heat of vaporization = 2257 kJ/kg, specific heat (liquid water) = 4184 $\frac{J}{kg \cdot K}$, specific heat (solid ice) = 2050 $\frac{J}{kg \cdot K}$, density of liquid water = 1000 $\frac{kg}{m^3}$.

(a) A steel pan (thermal conductivity of steel is $k = 46 \frac{W}{m \cdot K}$ with a radius of 8.0 cm and thickness of 7.0 mm contains 1.5 L of water. We put the pan on an electric stove that reaches a temperature of $300^o C$. Assume no heat is lost. How much time does it take to evaporate all the water once it is boiling?

(b) A mixture of 1750 g of water and 250 g of ice is in an initial equilibrium state at $0^o C$. The mixture is then brought to a second equilibrium state via a reversible process. In the second equilibrium state, the water-ice ratio, by mass, is 1:1 at $0^o C$. Calculate the entropy change of the combined water and ice in this process.

## 5 Thermal processes 2 - 15 points

We consider an ideal gas with adiabatic exponent $\gamma = 4/3$.

(a) Find the volume specific heat $C_V$ of this gas. Hint: $C_V$ is not $(3/2)R$, since $\gamma \neq 5/3$. Here, you can use the fact that for any ideal gas, the difference between the volume specific heat $C_V$ and the pressure specific heat $C_P$ is $C_P - C_V = R$.

(b) How many atoms are in one molecule of this gas?

We take a sample of this gas that occupies a volume of 5.00 liters, at a temperature of 300 K and a pressure of 100 kPa. The gas is compressed adiabatically to 1/5 of its original volume. Next, its temperature is brought back to 300 K while holding the volume constant. Finally, the gas isothermally expands back to its original volume.

(c) Sketch the pV diagram of the cycle. Indicate any important points, and make sure to put them at the right positions (i.e. calculate symbolically any values of $p$ and $V$, and write down your calculations). Don't forget to properly label your axes. Indicate the direction of the cycle with arrows.

(d) In the second step of the cycle, do you need to cool down or heat up the gas to let it return to its original temperature of 300 K? Explain your answer.

(e) Find the work done on the gas in the entire cycle.

(f) Could this cycle be used as a heat engine? If so, calculate its efficiency. If not, find another application that it could be used for, and calculate its associated coefficient of performance (COP = (what we get out)/(what we put in)).

(g) What should the total change in entropy of the cycle be? Explain your answer.

(h) By directly calculating, find the change in entropy in each of the three steps. (Note: obviously, you can check your answer by summing the contributions of the individual steps to get the total change in (g). However, here you should calculate them explicitly, not use what you know about the total change).