CENTRALE COMMISSIE VOORTENTAMEN NATUURKUNDE

PHYSICS EXAM

Date	: Wednesday 22 April 2026
Time	: 13:30 tot 16:30
Number of questions	: 5
Number of answer sheets	: none

Each question must be answered on a separate sheet (because each question is marked by separate examiner).

State your name on every sheet you hand in.

Do not write in pencil and do not use Tipp-Ex or any similar product.

Answers without argumentation will not be deemed correct.

Additional data can be found in the BINAS science data reference book (4th or 5th edition).

The standardized scores are:

Question 1	: 20 points
Question 2	: 18 points
Question 3	: 14 points
Question 4	: 14 points
Question 5	: 13 points

The marks are calculated as: mark = score / 79 * 9 + 1

Information concerning the procedure and progress of the process of marking see www.ccvx.nl > marking procedure and progress.

QUESTION 1 - crash test

The quality of seat belts is tested using crash tests. A car seat is mounted on a cart, with a dummy seated in it and secured by a seat belt.

The cart including the dummy is placed on rails, with its rear end touching a plate attached to the end of a fully relaxed spring. See Figure 1A. This represents the equilibrium position u = 0.
The cart is then pulled 15 m to the left, so that the spring is compressed. See Figure 1B.
The following formula applies to the “cart + dummy with spring” system:

$F_{back}(t) = -C \cdot u(t)$ with $F_{back}(t)$ is the force of the spring on the cart in N
u(t) is the function of the spring’s displacement from the equilibrium position in m
C is the spring constant in Nm^{-1}

The motion from 1B to 1C can be interpreted as part of a harmonic oscillation.
The “launch” takes place from the position shown in Figure 1B. Starting at time t = 0 s, the cart is accelerated over a distance of 15 m. Upon returning to the equilibrium position (Figure 1C), the cart loses contact with the spring.

From this moment on, the cart moves at a constant speed of 13.9 ms^{-1}. See Figure 1D.

After some time, the cart collides with a very heavy block of concrete; see Figure 1E.

Frictional forces may be neglected in this question.

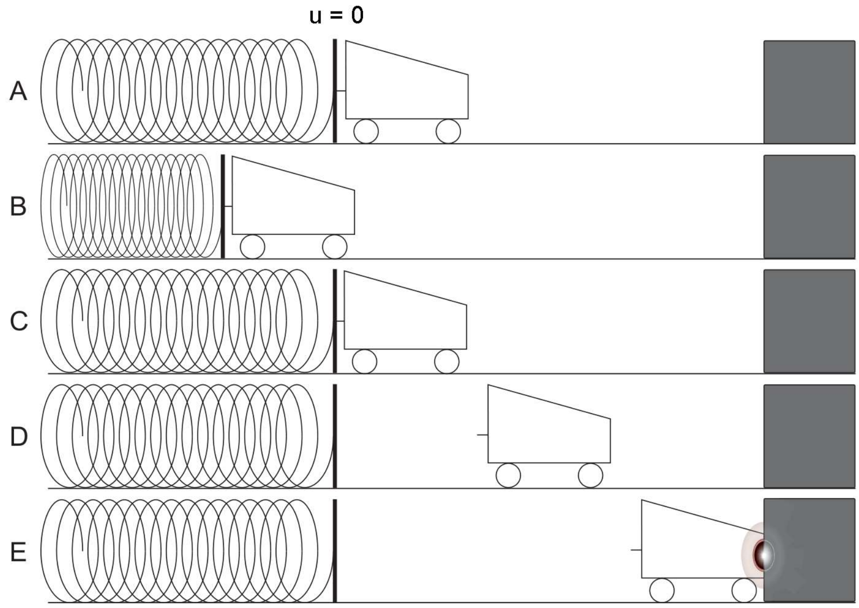


fig. 1

The mass of the cart is 1325 kg; the dummy has a mass of 75 kg.

3p a. Using the law of conservation of energy, calculate the spring constant.

Casper creates a model for the motion of the cart from B to C.
The computer model is shown in Figure 2. In the model, two model formulas and an initial value are incomplete. The model stops when the cart reaches position C.

	Model formulas	Start values
1	$F_{back} = -C \cdot u$	t = 0 (s)
2	a = ...	dt = 0,01 (s)
3	$v = v + a \cdot dt$	v = 0 (m/s)
4	$u = u + v \cdot dt$	C = (answer a)‡
5	t = t + dt	u = ... (m)
6	$E_k = 0{,}5 \cdot m \cdot v^2$	m = 1400 (kg)
7	IF ... THEN stop ENDIF	

‡ The answer to question 1a is not necessary to complete the model.

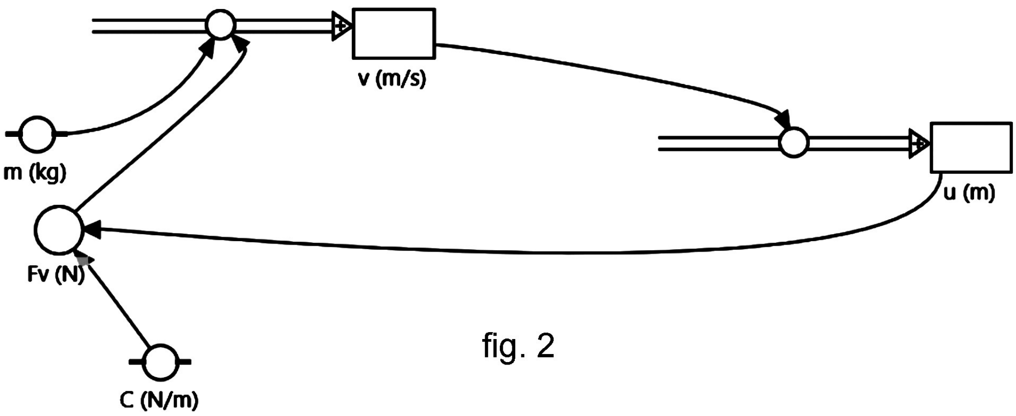


fig. 2

1p b1. Provide the formula for a on line 2 that should be used in the model.
1p b2. State the condition that must be entered in the IF ... THEN statement on line 7.
1p b3. Explain whether the initial value u = 15 (m) or u = -15 (m) should be entered on line 5.

2p c. Explain why the motion does not have constant acceleration..

Figure 3 shows the (v,t) diagram of the motion from B to C. It can be seen that the cart returns to its equilibrium position after 1.7 s.

2p d. Use a calculation to show that the motion from B to C indeed takes 1.7 s.

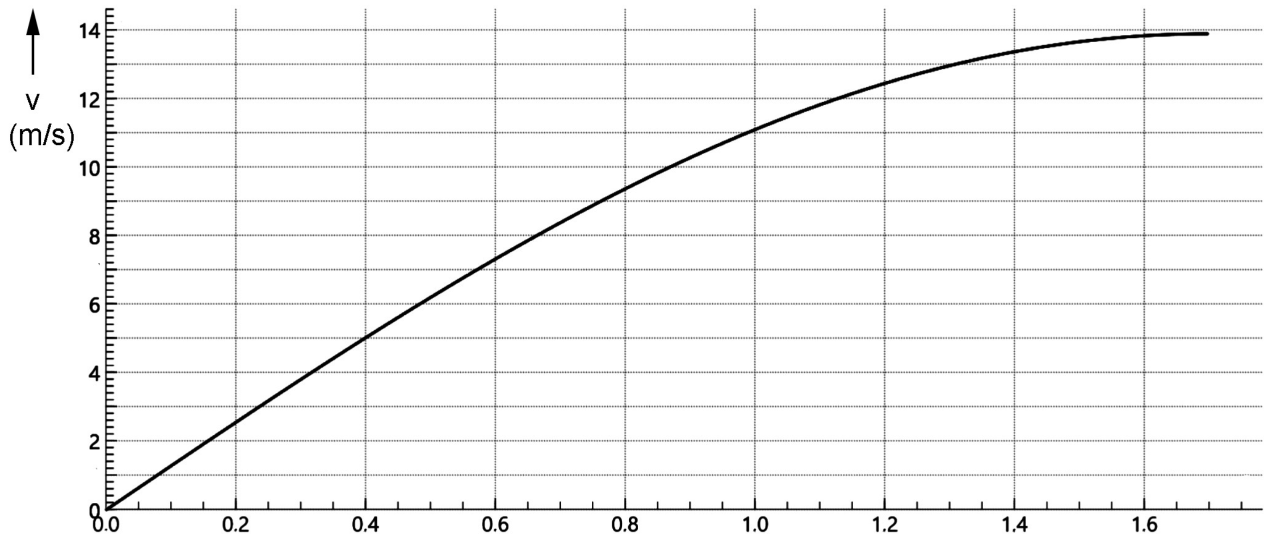


fig. 3

Figure 4 shows the change in kinetic energy of the cart as it moves from B to C.

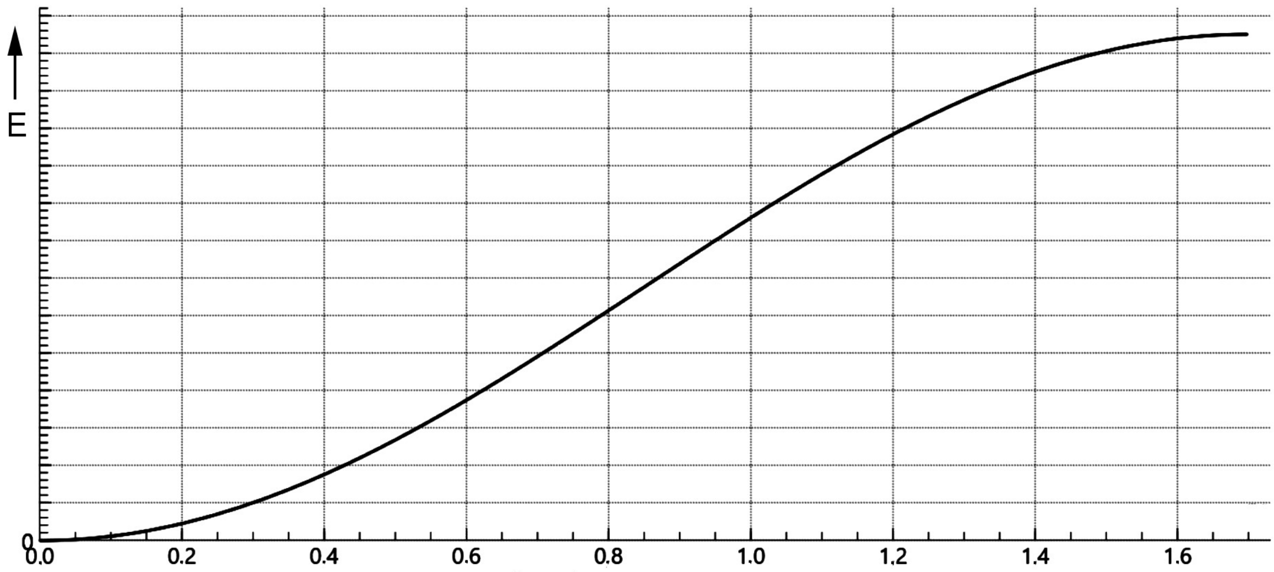


fig. 4

3p e. Explain why the period in Figure 4 is half the period in Figure 3.

After the cart with the dummy has performed a uniform motion from C to D, the cart collides with the concrete block and comes to a stop in 70 ms. During this time interval, the dummy does not decelerate.

4p f. Calculate the average braking force on the cart during the collision.

For motion with constant acceleration, the following applies: $x(t) = \frac{1}{2} a t^2$.

The dummy is held in the car seat by the seat belts. Due to the stretching of the seat belt, the dummy's center of mass comes to rest 35 cm <u>after</u> the collision.

3p g. Calculate the average deceleration experienced by the dummy until the dummy comes to rest.

QUESTION 2 - capacitor

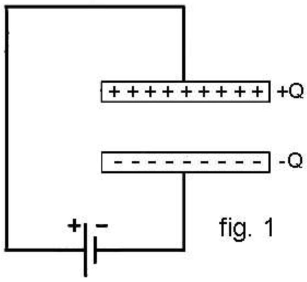


fig. 1

A capacitor is used to store electrical charge. A capacitor consists of two conductive plates with a relatively large surface area, which are positioned close together and separated by a non-conductive material or a vacuum. The setup is shown schematically in Figure 1.

When capacitor C is connected to a voltage source, the plates of the capacitor become charged with electric charges +Q and -Q.
As long as the capacitor continues to accumulate charge, the voltage U across the capacitor continues to rise. When the capacitor is fully charged, the voltage across the capacitor plates equals to the voltage of the voltage source.

We built the circuit shown in Figure 2. With this circuit, the capacitor can be charged by opening switch S_2 and then closing switch S_1. The charged capacitor can then be discharged through resistor R by opening S_1 and then closing S_2.

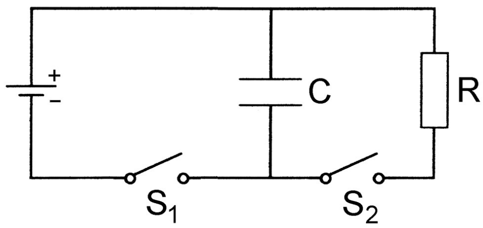


fig. 2

The voltage source supplies a voltage of 10 V.
The value of resistor R is 750 Ω.

The capacitor is fully charged and then discharged.

To measure the current during discharge, a current meter is to be included in the circuit.

2p a. Draw the complete circuit in this situation with the current meter in the correct position.

As the capacitor discharges, the voltage it delivers decreases.
Figure 3 shows the voltage of the capacitor versus time during discharge.

3p b. Calculate the discharge current immediately after closing switch S_2.

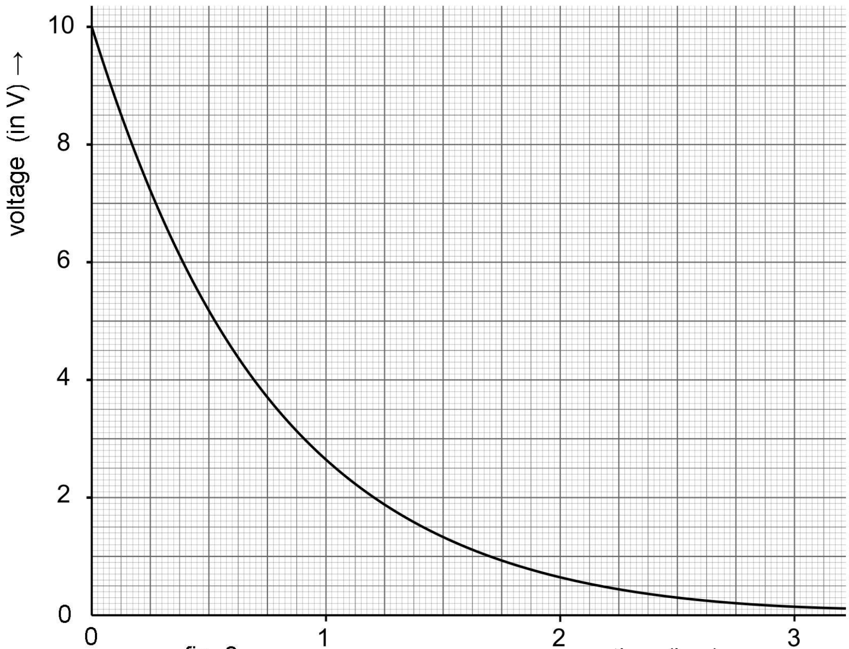


fig. 3

A LED is then connected in series with resistor R. See Figure 4. Switches S_1 and S_2 are closed.

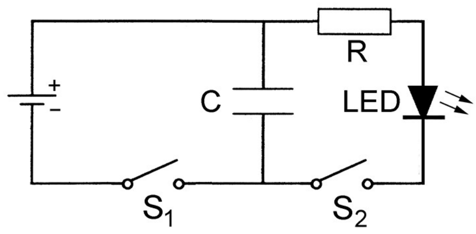


fig. 4

Figure 5 shows the U-I characteristic of this LED.

The LED turns on when the voltage exceeds the so-called "threshold voltage." The threshold voltage of the LED used is 1.7 V.

3p c. Using Figure 5, explain
- what the resistance of the LED is at a voltage of 1.5 V.
- how the resistance of the LED changes when the voltage exceeds the threshold voltage.

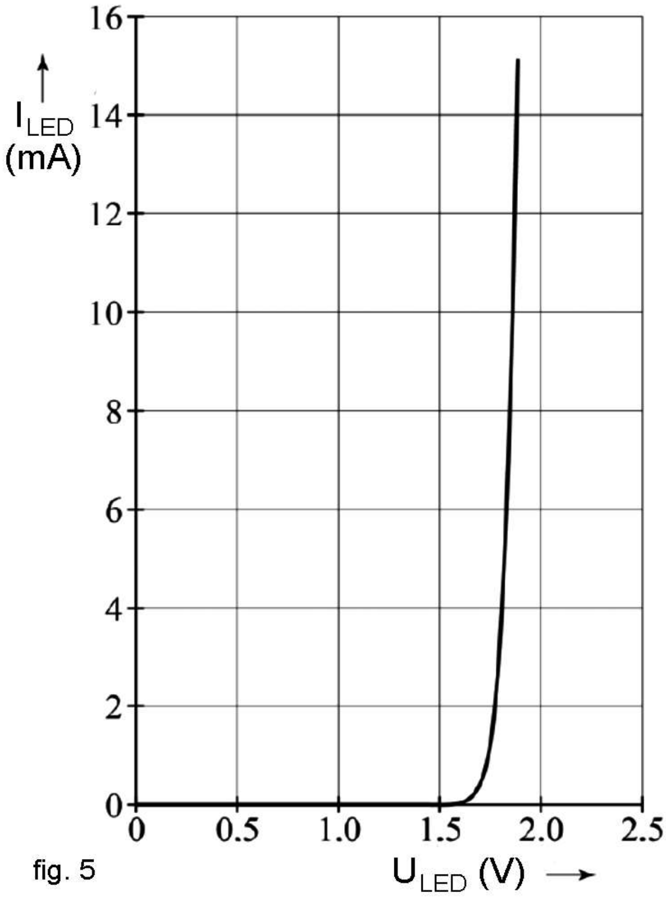


fig. 5

A LED cannot be considered to really have a "resistance". Instead, we speak of a voltage drop. Assume that the voltage drop across the LED is equal to the threshold voltage. This means that the voltage across the LED is always 1.7 V when it is turned on.

If the current drops below 1.5 mA, the LED turns off.

The capacitance of a capacitor is its ability to store an electric charge at a given voltage. The more charge a capacitor can store per volt, the greater its capacitance. Capacitance is measured in farads.
The following formula applies:

$C = Q / U$ With C the capacitance of the capacitor in farads,
Q the charge in coulombs, and U is the voltage in volts.

You can therefore think of a capacitor as a rechargeable mini battery.The “*capacity*” of the battery is always indicated on a rechargeable battery. It is usually measured in the unit mAh. This “*capacity*” has a different unit than the Farad.
If a battery has a “*capacity*” of 800 mAh, it can supply 800 mA for 1 hour or 200 mA for 4 hours.

Note: the capacitance of a capacitor differs from the “*capacity*” of a battery. That is why we write “*capacity*” in quotation marks and italics in this question when we mean the capacity of the battery.

3p d. Derive the unit of the aforementioned “*capacity*” in mAh in terms of SI base units as listed in Table 3 of Binas.

Take another look at Figure 4. S_2 remains open, S_1 is closed, causing the capacitor to charge. When the capacitor is charged, S_1 is opened. By then closing S_2, the capacitor discharges through the resistor and the LED. The LED turns on.

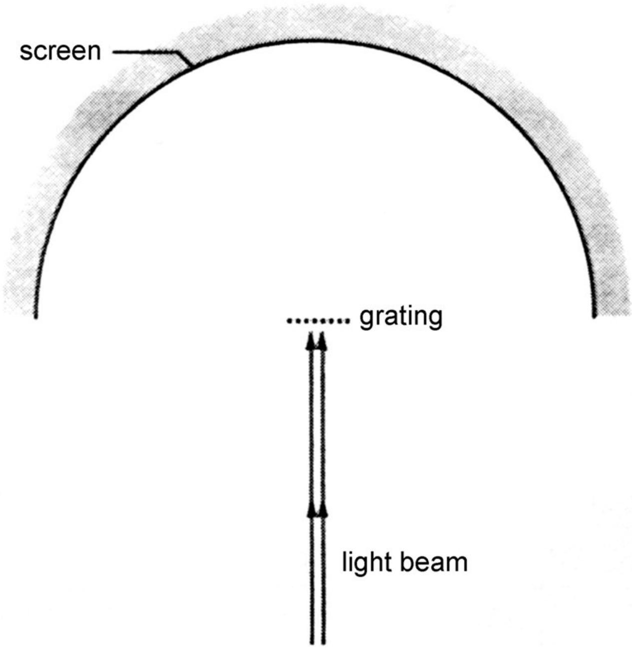
Capacitor C has a capacitance of 1.0 mF, resistor R has a resistance of 750 Ω, and the voltage source supplies a voltage of 10 V.

4p e. Show that the LED turns off again 0.95 s after S_2 is closed.

Now, using Figure 3, the “*capacitance*” referred to in question d can also be determined.

2p f1. Using Figure 3, determine the average voltage in the interval from t = 0 to t = 0.95 s.
1p f2. Use this to calculate the “*capacitance*” in mAh.

QUESTION 3 - light



Beams of various kinds of light are shone perpendicular onto a diffraction grating, one type after another.

The grating has 200 slits per mm.
A semicircular screen is positioned behind the grating so that the entire interference pattern is always projected onto the screen. The setup is shown schematically in the figure.

First, laser light with a wavelength of 633 nm is directed onto the grating.

4p a. Calculate how many maxima are visible on the screen.

Next, a narrow beam of white light is shone onto the grating. The beam contains only visible light with wavelengths between 400 nm and 700 nm.
Color spectra are now visible on the screen. A white line is visible in the center of the screen.

2p b. Explain the emergence of the white line.

4p c. Argue whether the spectra are oriented with the red or the violet side facing the white line.

In water, the speed of light is lower than in air. We want to investigate whether this affects what is visible on the screen.
We place the entire setup at the bottom of an aquarium filled with water.

4p d. Explain whether anything changes on the screen with the white line and the colored spectra. If so, explain what changes; if not, explain why not.

QUESTION 4 - neutrinos

Neutrinos are electrically neutral elementary particles that travel through matter practically unaffected.They are produced during nuclear fusion reactions, including those in nuclear power plants.

The mass of neutrinos is very difficult to measure because they have an extremely small mass. Suppose that neutrinos have a mass of $2 \cdot 10^{-37}$ kg.

4p a. Calculate the energy equivalent of the estimated mass in eV.
Give your answer with the correct number of significant figures.

Particles with mass cannot quite reach the speed of light.
Suppose that neutrinos have a speed of 99.995% of the speed of light.

3p b. Calculate the De Broglie wavelength of these neutrinos.

A neutrino detector consists, among other things, of an underground reservoir containing a large amount of water. The water molecules primarily contain oxygen atoms of the isotope O-16. When a neutrino collides with a particle in the nucleus of an oxygen atom, the neutrino can “disappear” and an electron leaves the nucleus of the oxygen atom. Below the first part of this reaction equation is given, in which the neutrino is denoted by the symbol ν.

$$^{16}_{8}\mathrm{O} \quad + \quad ^{0}_{0}\nu \quad \longrightarrow \ . \ . \ . \quad + \quad . \ . \ .$$

4p c. Copy this equation and complete the reaction equation.

A nuclear power plant produces $1.1 \cdot 10^{20}$ neutrinos per second. These neutrinos leave the plant uniformly in all directions. A neutrino detector is located 1.5 km away from the nuclear power plant.

3p d. Calculate the number of neutrinos produced by the plant that reach the detector per second per m².

continued on the next page ☞

QUESTION 5 - balloons

In a basket suspended beneath a hot air balloon, one can take scenic flights through the air.
Before the balloon can take off, it must be filled with hot air. This is done using a large fan that blows hot air into the balloon while it lies spread out on the ground.
When the balloon is inflated, it has a diameter of 18 meters. Its volume can be approximated by the volume of a sphere.

The fan has an electrical power of 750 W and inflates the balloon in 25 minutes, after which it is full and spherical. The density of air is 1.18 kg m^{-3}. The fan propels the air at a speed of 6.0 m s^{-1}.

4p a. Calculate what percentage of the electrical energy is converted into kinetic energy of the air.

In addition to this hot air balloon, there is a second balloon. This balloon has different dimensions. The outside air temperature is 22 °C. The air pressure is 1009 hPa.
The mass of 1 mol of air is 29 g. Assume that the volume of the balloon remains constant at 2800 m^3 after inflation. Just before takeoff, the air in the balloon is heated with a large gas burner.

Heating causes the air in the balloon to expand and partially escape from the balloon.
This lifts the balloon off the ground, and a moment later it is above the basket.
When 581 kg of air has escaped, the balloon has become light enough that the basket just lifts off the ground.
Ropes attached to the basket prevent the balloon and basket from taking off.
The air in the balloon may be considered an ideal gas.

3p b1. Calculate the mass of the air in the balloon before it is heated.
2p b2. Show that the temperature of the air in the balloon when the basket just lifts off the ground is 84 °C.

The second balloon can be approximated by a sphere with a diameter of 17.5 m.
The material the balloon is made of has a special heat-reflective coating and thus an effective thermal conductivity of 0.012 W m^{-1} K^{-1}.
The thickness of this material is 0.54 mm.

4p c. Calculate the heat flow from the balloon to the outside.

END