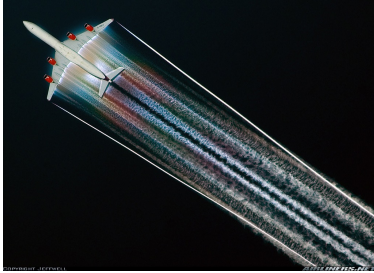


Physics 121.
Lecture 22.



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1

Bikes are everywhere!

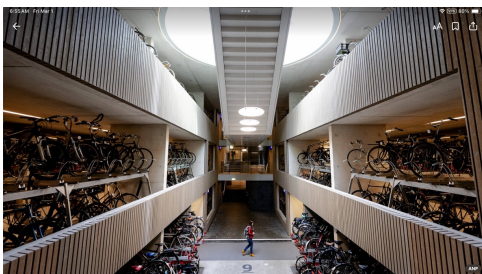


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2

The biggest parking garage for bicycles in the world! In Utrecht.



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3

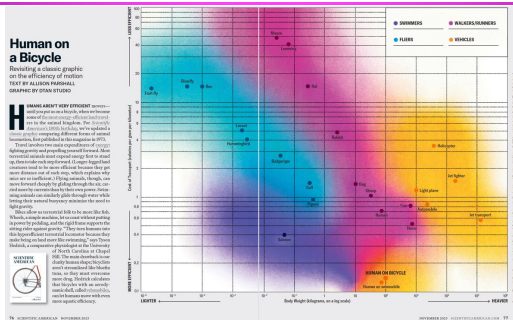
But where is Utrecht?
In the Netherlands of course!



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4

Biking is the most efficient way to get around.



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5

Physics 121.
Lecture 22.

- Course Information
- Topics to be discussed today: thermodynamic variables.
 - Temperature
 - Pressure

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Physics 121.
Lecture 22.

- Homework set # 8 is due on Saturday morning, April 18, at 8.30 am.
- Homework set # 9 is now available and will be due on Saturday morning, April 25, at 8.30 am.
- Exam # 3: April 28 at 8 am in Hubbell.

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Physics 121.
Lecture 22.

- At this point we have finished our discussion of the material that will be covered on Exam # 3 (Chapters 10, 11, 12, and 14).
- A few suggestions on how to prepare for exam 3:
 - Look at the results of exams 1 and 2 and see where you went wrong.
 - Review the solutions to the homework assignments. Did you find your solution using the easiest approach?
 - Complete the practice exam (without using the book as a reference) as a way to judge how well prepared you are for the exam.
 - Practice problem recognition using the end-of-the-chapter problems.
 - Seek help when you need help, but realize that there are limits to what the Physics 121 staff can do (we can not meet 4 hours a week with each of you individually).

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Physics 121.
Lecture 22.

- Material included on Exam # 3:
 - Chapter 10: all Sections except Section 10-10.
 - Chapter 11: all Sections except Sections 11-8 and 11-9.
 - Chapter 12: all Sections except Section 12-6, 12-7, and 12.8.
 - Chapter 14: all Sections.

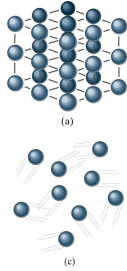
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9

Thermodynamics.

- The materials we encounter in our daily life can be considered to be made up out of atoms.
- In principle we can describe the macroscopic properties of these materials (such as temperature and volume) in terms of the microscopic properties of the individual atoms (such as velocity and inter-atomic forces).
- In practice this is very difficult.
- Thermodynamics is the field of physics that studies the description of the state of matter in terms of its macroscopic properties.



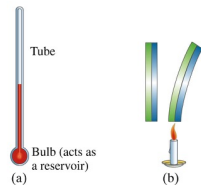
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10

Thermodynamic variables. Temperature.

- An important thermodynamic variable is temperature.
- Properties of many bodies change as their thermal environment is altered. For example, thermal expansion/contraction, pressure changes, etc.
- We can use these changes in properties to develop a tool that allows us to measure temperature: **the thermometer**.



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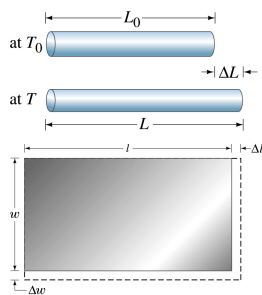
11

Thermal expansion. Linear expansion.

- When the temperature of a material increases, its length will increase:

$$\Delta L = \alpha L \Delta T$$

- The coefficient α is the coefficient of linear expansion. Typical values are $(0.5 - 10) \times 10^{-6} \text{ K}^{-1}$ at room temperature.
- Note: a solid will expand in every direction!!!!



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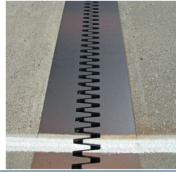
12

Thermal expansion. Linear expansion.

- In everything we design we need to consider the effects of thermal expansion:

- Draw bridges must be able to open in summer and winter.

- Airplanes expand in flight due to friction with the air! The width of the Concorde increases by a few cm during its flight.



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13

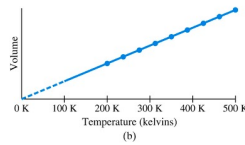
Thermal expansion. Volume expansion.

- When we deal with liquids we usually talk about volume expansion:

$$\Delta V = \beta V \Delta T$$

- The coefficient β is the volume expansion coefficient.

- The coefficient of volume expansion β is related to the coefficient of linear expansion α .



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14

Relation between volume and linear expansion.

- Consider a volume V whose temperature is increased by ΔT :

$$\Delta V = (L + \Delta L)(W + \Delta W)(H + \Delta H) - LWH =$$

$$= WH\Delta L + LH\Delta W + WL\Delta H =$$

$$= V \left(\frac{\Delta L}{L} + \frac{\Delta H}{H} + \frac{\Delta W}{W} \right) = V(3\alpha\Delta T)$$

- We see that $\beta = 3\alpha$.

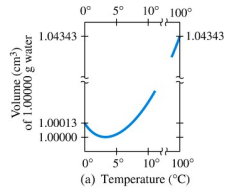
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15

Volume expansion. The water anomaly.

- Water has a very different thermal behavior from other liquids. It expands when it is cooled below 4°C.
- Its expansion continues even below the freezing point (frozen pipes). This is why ice cubes float!
- The anomalous behavior of water effects the way bodies of water freeze:
 - The body of water will cool down until it has a uniform temperature of 4°C.
 - Ice will form on top (life continues below).



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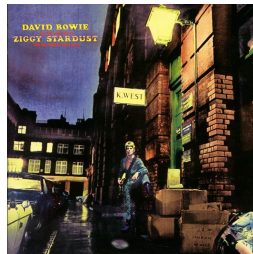
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3 Minute 24 Second Intermission.

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 24 second intermission.
- You can:
 - Stretch out.
 - Talk to your neighbors.
 - Ask me a quick question.
 - Enjoy the fantastic music.



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17

Thermodynamic variables. Measuring temperature.

- In order to measure the temperature of a system, we need to bring the thermometer in contact with the system.
- We must wait long enough to ensure that the thermometer and the system are in thermal equilibrium (have the same temperature).
- This approach relies on the **zeroth law of thermodynamics**:

Temperature is a property of a body, and two bodies are in thermal equilibrium if their temperatures are equal.
- If the thermometer initially has a different temperature than the system, energy will flow to provide thermal equilibrium and the temperature of both systems will change!

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Thermodynamic variables. Measuring temperature.

- In order to measure temperature we must:
 - Agree on a standard reference point to which we assign a certain temperature.
 - Agree on a unit.
 - Agree on a standard thermometer against which all other thermometers can be calibrated.
- The unit of temperature will be the Kelvin (K).
- The standard reference point is the triple point of water ($T = 273.16 \text{ K}$).



http://www.fluke.fr/common/prod_pages/pages/hart/products/tpw.htm

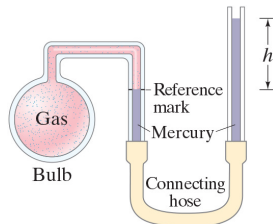
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Thermodynamic variables. Measuring temperature.

- The standard thermometer is the constant volume gas thermometer.
- The bulb of the thermometer, which is filled with gas, is put in thermal contact with the system to be studied.
- If nothing else would change, the change in pressure would change the mercury level.
- The reservoir on the right is now adjusted to change the mercury level so that the gas volume remains unchanged.



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Thermodynamic variables. Measuring temperature.

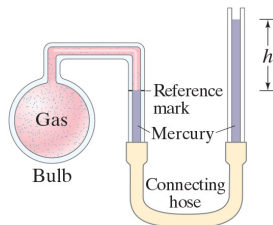
- The difference in height between the levels (h) is measured.
- The difference in height can be used to determine the pressure of the gas:

$$p = p_0 + \rho gh$$

where p_0 is the atmospheric pressure and ρ is the density of the mercury.

- The temperature of the body is defined in terms of the pressure p :

$$T = Cp$$



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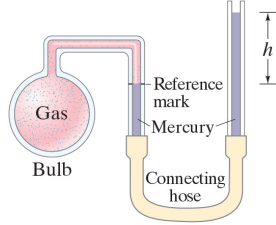
Thermodynamic variables. Measuring temperature.

- The definition of the temperature of the body in terms of the pressure p ($T = Cp$) requires us to determine one parameter (C).
- The device can thus be fully calibrated by bringing it in contact with a triple-point of water cell:

$$T_3 = 273.16 \text{ K} = Cp_3$$

or

$$C = 273.16/p_3$$



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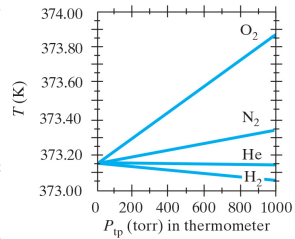
22

Thermodynamic variables. Measuring temperature.

- In general, we can thus find the temperature of the body by comparing the measured pressure with the triple-point pressure:

$$T = T_3 (p/p_3) = 273.16 (p/p_3)$$

- The method described here depends slightly on the amount and the type of gas in the bulb. However, this dependence is reduced when we use smaller and smaller amounts of gas.



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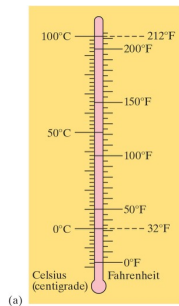
23

Thermodynamic variables. Temperature scales.

- The Kelvin is not frequently used in our daily life.
- More common temperature scales are the Celsius scale:
 - 0° is defined as the freezing point of water.
 - 100° is defined as the boiling point of water.

and the Fahrenheit scale:

- 32° is defined as the freezing point of water
- 212° is defined as the boiling point of water.



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Thermodynamic variables. Thermometers.

- Thermometers exist in many different forms.
- The design of a thermometer depends on how they are going to be used, and the range of temperatures to be measured.
- All thermometers rely on using macroscopic changes to measure temperature.
- For example, in the mercury thermometer, expansion or contraction of the mercury is used to measure temperature.



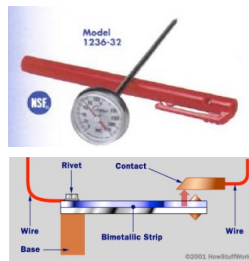
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Thermodynamic variables. Thermometers.

- Many thermometers rely on bimetals. Bimetals strips consist out of two different metals, connected to each other (side by side).
- When the temperature of the metals change, their length will change. If the changes in their lengths are different, the strip will bend.
- The change in shape of the strip can be used to move the dial of the thermometer, or open/close an electric circuit (in a thermostat).



<http://home.howstuffworks.com/therm2.htm>

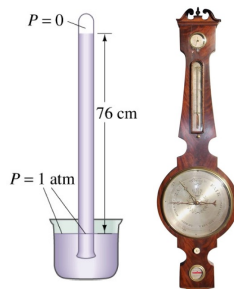
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Thermodynamic variables. Pressure.

- Pressure is an important thermodynamic variable.
- Pressure is defined as the force per unit area.
- The SI unit of pressure is the Pascal: $1 \text{ Pa} = 1 \text{ N/m}^2$. Another common unit is the atm (atmospheric pressure) which is the pressure exerted by the atmosphere on us ($1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2$).
- A pressure of 1 atm will push a mercury column up by 76 cm.



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Thermodynamic variables.
Pressure.

- Many devices that measure pressure, actually measure the pressure difference between the pressure of interest and the atmospheric pressure.
- Atmospheric pressure changes with altitude. The higher you go, the less air is pressing on your head! Airplanes use the atmospheric pressure to measure altitude.
- But keep into consideration that the atmospheric pressure at a fixed location and altitude is not constant!

The diagram shows two pressure-measuring devices. (a) An open-tube manometer with a U-shaped tube. The left side is open to the atmosphere at pressure P_0 , and the right side is connected to a system at pressure P . The height difference between the two liquid levels is h . (c) A tire gauge, which is a vertical tube with a spring at the bottom. The pressure P being measured is applied to the top of the tube, pushing it up against the spring. The scale reading is marked on the tube.

(a) Open-tube manometer

(c) Tire gauge

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Thermodynamic variables.
Pressure.

A weather map of North America showing pressure systems (High and Low pressure) and fronts (cold, warm, and stationary). The map includes a legend for precipitation (Rain, Snow, Mix, Ice, TS) and weather conditions (Clear, Partly Cloudy, Rain, Snow, Mix, Ice, TS, Haze, Smoke, Fog, Dust). The map is dated 1800 UTC Sat 18 Apr 2020.

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Done for today!
Next week: more temperature and heat!

A photograph of Earth as seen from the Moon's surface. The Earth is a large, bright, curved object in the sky, with the Moon's horizon visible in the foreground.

Earthset. Image Credit: NASA

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