Physics 115
General Physics II

Session 7

Mechanical energy and heat
Heat capacities
Conduction, convection, radiation

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- Home page: http://courses.washington.edu/phy115a/

Lecture Schedule (up to exam 1)

Date	Day	Lect.	Topic	readings in Walker
31-Mar	Mon	1	Introduction, Preview	
1-Apr	Tues	2	Density & Pressure	15.1-15.3
3-Apr	Thurs	3	Static Fluids, Buoyancy	15.4-15.5
4-Apr	Fri	4	Fluid Flow, Bernoulli	15.6-15.8
7-Apr	Mon	5	Viscosity, Flow, Capillaries	15.9
8-Apr	Tues	6	Temperature, expansion	16.1-16.3
10-Apr	Thurs	7	Heat, Conduction	16.4-16.6
11-Apr	Fri	8	Ideal gas	17.1-17.2
14-Apr	Mon	9	Heat, Evaporation	17.4-17.5
15-Apr	Tues	10	Phase change	17.6
17-Apr	Thurs	11	First Law Thermodynamics	18.1-18.3
18-Apr	**Fri**		**EXAM 1 Ch 15,16,17**	

Check the course home page

courses.washington.edu/phy115a/

for course info updates, and slides from previous sessions

Today

Announcements

Clickers that have been used but not registered

634653
666299
685050
685637
691769

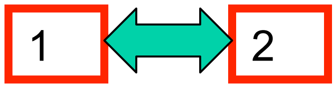
- **I will be away** all next week
  - Prof. Jim Reid will cover lectures and exam for me
  - Prof Reid has office hours next week – or you can see me after class today or tomorrow if necessary
- Clicker quiz results will be posted tomorrow
  - Check to make sure your clicker is being recorded
  - Web registration page will be closed tonight – if you have not registered by 6pm today, you must send email to phys 110 with your name, UW NetID, clicker number and screen alias.
- Exam 1 is one week from Friday (4/18)
  - Details and sample questions in class next week
- Volunteers to take exam at 2:30 instead of 1:30 : please go **HERE** (instead of URL shown Tuesday)

  https://catalyst.uw.edu/webq/survey/wilkes/232658
  - If you do **NOT** get an email from phy115a, you must take the exam next Friday at the regular class time, 1:30!!

Tuesday...Quiz 3

An alert student pointed out:

Strictly speaking, (A) should have said “no NET heat is transferred” between objects in equilibrium – heat energy is transferred, but goes both ways in equal amounts.



So I gave credit to answer B as well as C.

However: please interpret questions as **simply** as possible! I will not try to ‘catch’ you. Quizzes are intended to reinforce basic ideas.

- Two objects in physical contact with each other are in thermal equilibrium. Then
  A. No heat is being transferred between them
  B. They have the same temperature
  C. Both A and B are true
  D. Neither A or B is true

Announcement

The UW Society of Physics Students presents: a Spring Mixer

Come out to enjoy some good food and socialize with fellow students on Thursday, April 10th from 4:30p-6:30p in PAB, C520 where you can learn more about the people representing your interests as an undergraduate and find out how you can become involved in exciting projects and events.

Upcoming events

Weekly: Lunch Box Seminar: every Monday at 12:30p in PAB 135B

April 10th: Spring Mixer and Meet & Greet

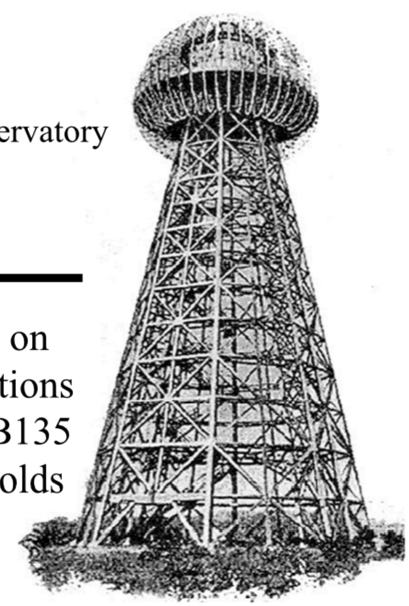
May 2nd: Science Cafe - 7p at Trabant Coffee & Chai

May 17th: Day of Physics - demos and tours of laboratories

May 31st: Trip to the Laser Interferometer Gravitational-Wave Observatory

June 6th: Science Cafe - 7p at Trabant Coffee & Chai

Please email us at uwspsofficers@gmail.com or find us on Facebook: UW SPS or Twitter: @UWSPS with any questions or comments. Or, officers can usually be found in PAB B135 anytime. The SPS is open to anyone of any major who holds an interest in science. We hope to see you soon.



Last time

2-Dimensional expansion

- Linear expansion → expansion of area, or volume
  - Area expansion = linear expansion in 2 dimensions

$$A' = (L + \Delta L)^2 = (L_0 + \alpha L_0 \Delta T)^2 = L_0^2 + 2\alpha L_0^2 \Delta T + \alpha^2 L_0^2 \Delta T^2$$

$$for \quad \alpha\Delta T << 1, \quad \alpha^2 \Delta T^2 \approx 0 \rightarrow A' \approx L_0^2 + 2\alpha L_0^2 \Delta T = A + 2\alpha A\, \Delta T$$

$$\Delta A = A' - A = 2\alpha A\, \Delta T$$

Notice: not proportional to α^2 , but 2α

  - Volume expansion: same idea, now we get factor 3α

$$V' = (L + \Delta L)^3 = (L_0 + \alpha L_0 \Delta T)^3$$

$$for \quad \alpha\Delta T << 1, \quad \Delta V = V' - V = 3\alpha V\, \Delta T$$

  - However, we define a volume coeff of expansion β :

$$\Delta V = \beta V \Delta T \rightarrow \beta \approx 3\alpha$$

Last time

Thermal expansion

- Most materials expand when heated
  - Basis of simple liquid thermometers
  - Approximately linear with T

$$\Delta L \propto \Delta T \rightarrow \Delta L = (const)\Delta T = \alpha L_0 \Delta T$$

  - L_0 = original length of object
  - Coefficient of linear expansion α : units = 1/°C (or 1/K)

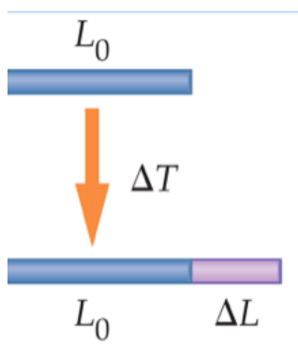


TABLE 16–1 Coefficients of Thermal Expansion near 20 °C

Substance	Coefficient of linear expansion, $\alpha(K^{-1})$
Lead	29×10^{-6}
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Iron (steel)	12×10^{-6}
Concrete	12×10^{-6}
Window glass	11×10^{-6}
Pyrex glass	3.3×10^{-6}
Quartz	0.50×10^{-6}

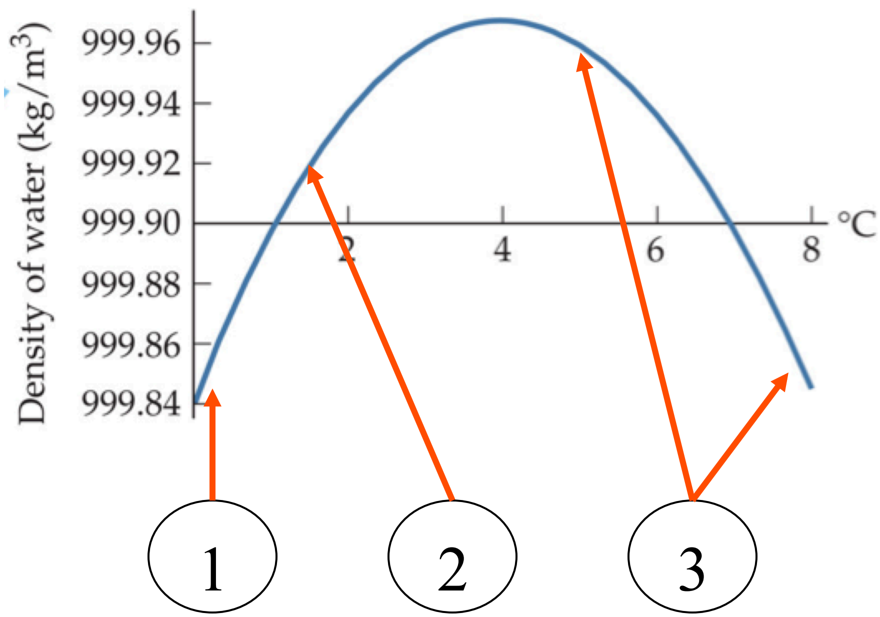
VOLUME COEFFICIENTS

Substance	Coefficient of volume expansion, $\beta(K^{-1})$
Ether	1.51×10^{-3}
Carbon tetrachloride	1.18×10^{-3}
Alcohol	1.01×10^{-3}
Gasoline	0.95×10^{-3}
Olive oil	0.68×10^{-3}
Water	0.21×10^{-3}
Mercury	0.18×10^{-3}

Demonstration last time

But...Water is special!

- Thermal properties of water are different from most substances
  - Solid is less dense than liquid
  - Density of water (at 1 atm) is max at ~ 4 °C



Demonstration last time:

Flask of water: V indicated by height of column

1. Started at ~ 0°C, slowly warmed up to room temp
2. At first, V dropped (column fell below starting point): Same m, but <u>higher</u> density → V smaller
3. Later (after T>4°C), V increased (water column rose above starting point: <u>Lower</u> density → V larger

Thermal expansion example

- A solid steel beam is 20m long, with cross section 20cm x 30 cm

- Compare its length, cross sectional area, and volume, between
  - a very cold day, when T= –20°C , and
  - a very hot day, when T= +40°C

$$\Delta L = \alpha L_0 \Delta T$$

$$= \left[1.2\times10^{-5}\,(\mathrm{C}°)^{-1}\right]\left(20\ \mathrm{m}\right)\left[40.0°\mathrm{C} - (-20.00°\mathrm{C})\right] = 0.0144m \quad (1.4cm)$$

$$\Delta A = 2\alpha A_0\ \Delta T$$

$$= 2\left[1.2\times10^{-5}\,(\mathrm{C}°)^{-1}\right]\left(0.2m\times0.3m\right)\left[60°\mathrm{C}\right] = 8.6\times10^{-5}m^2 \quad (0.86cm^2)$$

$$\Delta V = \beta V_0 \Delta T \rightarrow \beta \approx 3\alpha$$

$$= 3\left[1.2\times10^{-5}\,(\mathrm{C}°)^{-1}\right]\left(0.2m\times0.3m\times20m\right)\left[60°\mathrm{C}\right] = 2.6\times10^{-3}m^3 \quad (2600cm^3)$$

Heat capacity and specific heat

C is the **heat capacity**, the heat transfer required to change an object's temperature by 1K

c is the **specific heat capacity**, the heat capacity per unit mass for a given substance, so **c = C/m**.

Heat capacity and specific heat:

$$\boxed{Q = C\,\Delta T = mc\,\Delta T}$$

Heat units: 1 cal = 4.186 J = energy to raise T of 1 cm^3 of water by 1K.

1 Cal = 1 kcal = 4186 J,

1 Btu = energy to raise T of 1 lb of water by 1°F = 252 cal = 1.055 kJ

$$c_{\text{water}} = 1\ \text{cal/(g}\cdot\text{K)} = 1\ \text{kcal/(kg}\cdot\text{K)} = 4.184\ \text{kJ/(kg}\cdot\text{K)} = 1\ \text{Btu/(lb}\cdot{}^\circ\text{F)}$$

Specific heats of common substances

Table 18-1 Specific Heats and Molar Specific Heats of Some Solids and Liquids

Substance	c, kJ/kg·K	c, kcal/kg·K or Btu/lb·F°	c', J/mol·K
Aluminium	0.900	0.215	24.3
Bismuth	0.123	0.0294	25.7
Copper	0.386	0.0923	24.5
Glass	0.840	0.20	—
Gold	0.126	0.0301	25.6
Ice (−10°C)	2.05	0.49	36.9
Lead	0.128	0.0305	26.4
Silver	0.233	0.0558	24.9
Tungsten	0.134	0.0321	24.8
Zinc	0.387	0.0925	25.2
Alcohol (ethyl)	2.4	0.58	111
Mercury	0.140	0.033	28.3
Water	4.18	1.00	75.2
Steam (at 1 atm)	2.02	0.48	36.4

Liquids are in red typeface and gases are in blue typeface.

Example: heat capacity

A gold miner wants to melt gold to fill molds and make ingots.

How much heat is needed to increase the temperature of 3.0 kg of gold from 22°C (room temperature) to 1,063°C, the melting point of gold?

$$Q = mc\,\Delta T = (3.00\text{ kg})[0.126\text{ kJ/(kg}\cdot\text{K)}](1063°C - 23°C) = 393\text{ kJ}$$

Note: this gets us up to the melting T, but **more** heat will be needed to actually melt the gold... More later

Quiz 4

- The specific heat of gold is about 1/3 that of copper.
- 1 kg of each metal is at room temperature.
- If you add 1 kcal of heat to each, which one's temperature rises more?

A. Copper

B. Gold

C. Both have the same ΔT

D. I need more information to answer

$$Q = mc\Delta T \rightarrow \Delta T = Q / mc$$

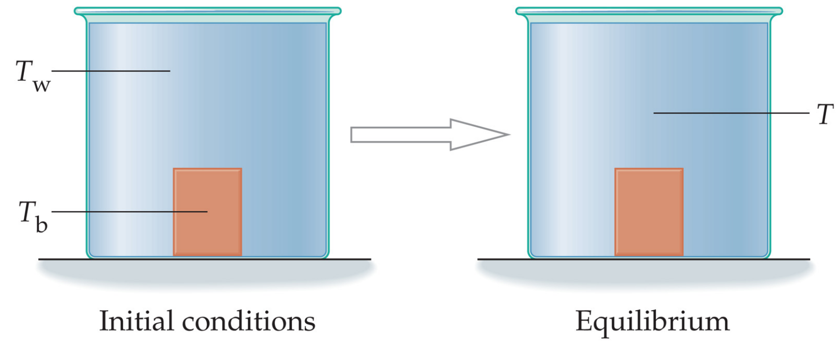
$$\boxed{so\ \Delta T \propto (1/c),\ \text{for same m and Q: } \mathrm{c}_{\text{gold}} < \mathrm{c}_{\text{copper}} \rightarrow \Delta T \text{ greater for gold}}$$

$$\text{Gold: } \Delta T = 1kJ / (1kg \cdot \left(0.126kJ / kg \cdot K\right) = 7.9\,K$$

$$\text{Copper: } \Delta T = 1kJ / (1kg \cdot \left(0.386kJ / kg \cdot K\right) = 2.6\,K$$

Measuring specific heats: calorimetry

- Calorimeter: device for measuring heat capacities, or heat content of objects
  - Thermally isolated (insulated) container holds known mass of (for example) water
  - Insert object of known T, mass M
  - Wait until water and object are in thermal equilibrium
  - Measure final T (same for water and object)



Isolated: no net change in total heat energy of M and water

$$\Delta Q_{SYSTEM} = \Delta Q_{M} + \Delta Q_{W} = 0 \quad \text{(heat lost by M = heat gained by water)}$$

$$Mc_M \Delta T_M + m_W c_W \Delta T_W = 0, \qquad \Delta T = T_{FINAL} - T_{INITIAL}$$

$$Mc_M (T - T_{M0}) + m_W c_W (T - T_{W0}) = 0$$

$$c_M = \frac{m_W c_W \left(\Delta T_W\right)}{\left(-\Delta T_M\right) M}$$

Note: if we know c_M, we can find final $T = \dfrac{Mc_M T_{M0} + m_W c_W T_{W0}}{\left(Mc_M + m_W c_W\right)}$

Example: measuring specific heat

To measure the specific heat of lead, you heat 600 g of lead shot to 100°C and place it in an insulated aluminum calorimeter of mass 200 g that contains 500 g of water, initially at 17.3°C. The specific heat of the aluminum container is 0.900 kJ/(kg·K).

If the final temperature of the system is 20°C, what is the specific heat of lead measured this way?

Notice: Pb cools, (water + container) get warmer

$$\Delta Q_{\mathrm{Pb}} = -m_{\mathrm{Pb}} c_{\mathrm{Pb}} \Delta T_{\mathrm{Pb}} \text{ (heat } \textit{lost} \text{ by Pb)} \qquad \Delta Q_{\mathrm{w}} = m_{\mathrm{w}} c_{\mathrm{w}} \Delta T_{\mathrm{w}} \qquad \Delta Q_{\mathrm{c}} = m_{\mathrm{c}} c_{\mathrm{c}} \Delta T_{\mathrm{c}}$$

$$\Delta Q_{\mathrm{Pb}} + \Delta Q_{\mathrm{w}} + \Delta Q_{\mathrm{c}} = 0$$

$$m_{\mathrm{Pb}} c_{\mathrm{Pb}} \Delta T_{\mathrm{Pb}} = m_{\mathrm{w}} c_{\mathrm{w}} \Delta T_{\mathrm{w}} + m_{\mathrm{c}} c_{\mathrm{c}} \Delta T_{\mathrm{c}} = \left(m_{\mathrm{w}} c_{\mathrm{w}} + m_{\mathrm{c}} c_{\mathrm{c}}\right) \Delta T_{\mathrm{w}}$$

$$c_{\mathrm{Pb}} = \frac{\left(m_{\mathrm{w}} c_{\mathrm{w}} + m_{\mathrm{c}} c_{\mathrm{c}}\right) \Delta T_{\mathrm{w}}}{m_{\mathrm{Pb}} \Delta T_{\mathrm{Pb}}} = \frac{\left[(0.50 \text{ kg})(4.18 \text{ kJ}/\left(\text{kg} \cdot \text{K}\right)) + (0.20 \text{ kg})(0.90 \text{ kJ}/\left(\text{kg} \cdot \text{K}\right))\right](2.7\text{K})}{(0.60 \text{ kg})(80.0\text{K})}$$

$$= 0.128 \text{ kJ}/\left(\text{kg} \cdot \text{K}\right)$$