



uOttawa

PHY1321 AND PHY1331  
Principles of Physics  
LECTURE NOTES

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Fall 2016

Lecture Notes

to accompany "Physics for Scientists and Engineers"  
by Serway and Jewett (9<sup>th</sup> edition)

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The notes cover chapters 1-8, 10-12, 14, 19-22 from the textbook (16 in total -- one third of the textbook).

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## PHY1321/31 Fall 2016 Tentative (and Optimistic!) Course Schedule:

PHY1321/1331A

PHY1321/1331B

### PART I THERMODYNAMICS

1	Sept 7	Intro Class	Sept 9
2	Sept 12	State Variables: Pressure and Temperature	Sept 13
3	Sept 14	Ideal Gas Law: PV diagram	Sept 16
4	Sept 19	First Law of Thermodynamics	Sept 20
5	Sept 21	Internal Energy, Work and Heat in Gas Transitions	Sept 23
6	Sept 26	Summary of Thermodynamics I	Sept 27
7	Sept 28	Kinetic Theory of Gases I	Oct 30
8	Oct 3	Kinetic Theory of Gases II	Oct 4
9	Oct 5	Heat Engines	Oct 7
10	Oct 12	Entropy /Summary of the Thermodynamics II	Oct 11

### MIDTERM I

Oct 15

### PART II REVIEW OF LINEAR DYNAMICS

11	Oct17	Kinematics I	Oct 14
12	Oct 19	Kinematics II	Oct 18
13	Oct 31	Dynamics I	Nov 21
14	Nov 2	Dynamics II	Nov 1
15	Nov 7	Energy, Work	Nov 4
16	Nov 9	Linear Momentum/Centre of Mass	Nov 8
17	Nov 14	Centre Of Mass	Nov 11
18	Nov 16	Rotational Motion I	Nov 15
19	Nov 21	Rotational Motion II	Nov 18
20	Nov 23	Rotational Motion III	Nov 22

### MIDTERM II

Nov 26

21	Nov 28	Fluids I	Nov 25
22	Nov 30	Fluids II	Nov 29
23	Dec 5	Strategic Reserve	Dec 2
24	Dec 7	Strategic Reserve	Dec 6

Yes ,it is a lot! I have taught this course for last 13 years and only few times I have been able to discuss all of the topics listed above. Still, we will do our best.

## LIST OF THE ADDITIONAL PROBLEMS RECOMMENDED FOR SELF STUDIES

Every year I am asked by some students, is there anything else they should work on aside from assignments, the problems I solve for them in class and DGD questions.

This year I decided to compile the list of end of chapter problems, that students might want to focus on to get better results.

I divide these problems into two groups :STRAIGHTFORWARD and ADVANCED.

Students who are struggling the assignment questions are advised to try to solve problems form the STRAIGHTFORWARD group first.

To facilitate learning these problems should be attempted as soon as a given chapter is finished.

- 1 The only resource should to be used should be the self made formula sheet. All problems should be attempted "from the scratch" without consulting numerous resources ( internet, textbook).
- 2 Student should spend no more than 10 minutes per problem. Take notes of all his/hers calculations/diagrams and questions pertaining to the process.
- 3 If after 10 minutes the solution of the problem is not in sight, student should move on to the next problem.
- 4 After attempting at least 10 problems, student should re-visit the ones that have not yet been solved successfully.
- 5 Session of this sort should take between 60 and 120 minutes with 10 to 20 problems being attempted
- 6 The problems that have been attempted without success should be earmarked for future reference - student should approach the help center TA, their own DGD TA or professor to get help on some of these questions. In any case the problem should be annotated ( notes for future reference indicating clearly what was wrong with the used approach)
- 7 Successful session is the one in which 75% of the problems are solved correctly.

SUGGESTED TEXTBOOK PROBLEMS BY CHAPTER:

LOG

Chapter	STRAIGHTFORWARD	ADVANCED	UNABLE TO SOLVE	DATE:	HELPED BY:
	END OF THE CHAPTER PROBLEMS				
19	1;3;5;9;11;13;15;27;29; 31;33;35	17;39;41;43;			
20	1;3;5;9;17;19;21;23;31; 33;35;37;43;45;47	13;27;29;41;51			
21	1;3;5;7;9;11;13;15;17; 19;21;23;27;29;35;37;	25;33;39;41;43;45;52;5 3;55			
22	1;3;5;7;9;11;13;15;17; 19;21;23;25;51;55;57;5 9;61;63;65	27;29;31;35;53 67;71;73;75;77			
2	1;3;7;9;11;15;23;25;27; 9;45;47;49;61;63	19;21;35;37;51; 55;57;59			
4	1;3;5;7;11;13;15; 29; 33;37;39;41;45;47;49	9;17;19;21;23;25 41;43;51;53;55; 59;65;69			
5	1;3;5;7;9;11;15;53;55	15;31;33;35;37; 47;61;63;65;67			
6	1;3;5;7;9;11;21;23;27; 29	13;17;19;31;51;59			
7	1;3;5;7;9;11;15;17;31;33 ;35;41;47;49;51;53	25;29;39;43;59			
8	3;5;7;13;19;29;31;33; 43;	9;11;15;21;23;25;27;37; 39;45			
9	1;3;7;9;11;13;15;23; 25;27; 35; 37;45;48	17;19;21;31;33; 39;49;53;63;69;71;81;89			
10	1;5;7;9;15;17;19;21;29; 39;45;49	3;11;13;23;25;35 37;41;43;47;53;55			
11	1;3;5;7;11;13;23;25;31; 33;35;37	15;17;19;21;27; 29;41;51;55			
12	1;3;7;9;13;37;39	19;23;41;43;45;47			
14	1;3;7;9;11;13;19;21;25;2 7;29;31;41;43;51; 57;	17;23;33;35;36;37;39;4 3;45;47;49;53;55			

NOTE:

ALL PROBLEMS ARE FROM THE TEXTBOOK (Serway, Jewett for Scientists and Engineers, 9<sup>th</sup> Edition)

All problems listed in the above table have numerical answers at the back of the text.

I suggest starting the special exercise notebook where all the efforts are recorded, including the problems requiring help.

# HOW TO USE THESE NOTES?

THE PHY 1321/1331 LECTURE NOTES HAVE BEEN CREATED, COMPILED AND REFINED OVER THE COURSE OF LAST THIRTEEN YEARS WHILE I HAVE BEEN TEACHING THIS COURSE. /WHAT I AM SAYING HERE IS THAT THESE ARE VERY GOOD NOTES!/

## Why notes?

1. It is rather difficult to copy ppt slides during the lecture in a large auditorium equipped with small, foldable "elbow-rests" pretending to be tables.
2. Also, we will frequently solve problems from the textbook (end of chapter problems), so instead of carrying the heavy textbooks on campus, students should bring the notes and use them in class (annotate them, add their own notes/comments etc.) the same idea is behind putting the DGD problems at the end of your notes.

THE NOTES ARE MEANT TO BE READ BEFORE THE CLASS!

ALSO, EACH TOPIC LISTS CORRESPONDING CHAPTERS FROM THE TEXTBOOK. THERE ARE TWO SUBCHAPTERS FOR SELF - STUDY! (roughly 1% of the discussed material: THEY WILL NOT BE DISCUSSED IN CLASS BUT THEY ARE TESTABLE)

**IT IS ABSOLUTELY VITAL THAT STUDENTS READ THE NOTES BEFORE THE CLASS. (THAT IS ABSOLUTE MINIMUM OF PREPARATION FOR THE CLASS).**

**SERIOUS STUDENTS WOULD:**

- i) READ THE NOTES,
- ii) READ THE RELEVANT PART OF THE TEXTBOOK,
- iii) THINK ABOUT THE SUGGESTED PROBLEMS.
- iv) COMPLETE ONLINE PRE-LECTURE QUIZ (typically due before the given class)

During each lecture two more problems from the list will be solved (on average). The remaining problems are left for students as practice. 90% of the suggested problems are from the textbook. The solutions to the suggested problems will not be provided online (so don't ask!)

# How to study physics? Survival manual.

## What to expect in this course?

- How does this course compare with the high-school physics
- Advice from experienced instructor.
- Advice from your students who took this class in the past.
- Ground rules.

How does this course compare with the high-school physics

In the first semester of introductory course of Physics I am used to spending up to 40% to 50% of the semester ( this year I am planning to use 9 lectures only) on the review of classical mechanics that students know from high-school grade 11 and grade 12 physics.

(It is pretty much all of the mechanics that is studied in grade 12 high-school physics, there are some significant differences as illustrated by tables below:

**Table 1:**

### **Typical differences between the HS and First Year University class:**

<b>high-school</b> (class size: under 30)	<b>University</b> (class size under 300)
Teacher knows students	Teacher does not know students
Students know each other	Students don't know each other
Slower pace	Faster pace (10 times faster!)
Many tests focused on small parts of the material:	Fewer tests covering larger parts of the material
Credit recovery schemes, additional assignments	Marks are final and rarely disputed

**Table 2**

**What do we understand by feedback on the assignments and tests**

<b>high-school</b> (class size: under 30)	<b>university</b> (class size under 300)
Grade is split into the Understanding and Knowledge, Application, Communication	<b>One grade to rule them all!</b>
The graded paper includes personalized comments (always full of tenderness and care): One may read something like this: "Dear Jimmy you show a great talent in drawing small triangles, however your calculations of the trigonometric functions require some refining... Keep working on it! mark:20%"	<b>The grade is the feedback!</b> There will be no comments, or maybe something along the lines: "20%! F- Please see me immediately!"
Some parents successfully intervene with principals to rise their children grades.	<b>Grades are confidential and may not be discussed with third parties!</b>

**WARNING: PACE OF LECTURES**

I get the following a lot:

- "At first we were moving at nice slow pace and I was able to keep up; but then we just rushed through a lot of material very quickly!"
- I did not speed up! I actually moved at the same pace in the second half of the semester: 1 week per chapter (12 chapters all together)
- Naturally if the same amount of time is spend on the relatively familiar material as it is on the content that has never been introduced before, the latter will appear to be rushed through!

**Why Physics is perceived as "hard?"**

- Many students will claim that Physics is harder than other subjects studied by them.
- Almost all students will admit that success in Physics requires more work than similar success in other disciplines
- In the past I asked students if they agree with these statements, and asked them to try to think why is it so?

### Here is what I think...

- 1 University physics is perceived as hard as it requires operational knowledge of large areas of simple math.
- 2 **Majority of students are familiar with the relevant math content itself, but they have not internalized it.**  
(The mathematical ideas are not second nature to students in the same way as knowledge of English language is).  
As result majority of students need much more time to comprehend simple physical content expressed in the language of mathematics.
- 3 **Physics grades are established predominantly based on problem solving.**  
Even the students who were "very good in math" in HS (received 80% or better) would find the "text problems," to be the most difficult in the particular class.  
(Fortunately such text problems typically make up only up to 20% of any given math test).
- 4 *Guess what...*  
**In Physics all of the problems are really "applied math text problems!"**  
(Lots of "applied math" problems are from kinematics!)

### This is an opinion commonly presented by a students in physics classes

- "When I am in class I understand everything perfectly, I can follow the instructor without any problems. I also understand the textbook. It is only when I try to solve problems on my own that I have difficulty!"
- *Guess what?*  
Your grade is based almost entirely on your ability to solve problems!
- That means that you should spend 90% of your study time outside of the classroom on solving problems.
- In the words of immortal Richard Feynman:  
"You don't know anything until you practice..."

### This leads us to answer to the key question: How to study physics?

- It all depends on what do you want from this course both in terms of a grade as well as your own satisfaction and knowledge.
- Doing just the assignments and re-doing the problems from the lecture notes should give a solid base to pass a course with the grade in a C-B range.
- To get really strong in physics (A- or higher ) one will need to have a lot of practice.
- The end of the chapter (EOC) problems are great for practice. Every odd problem has the numerical solution at the end of the textbook. These problems should be practiced constantly by serious students.

As a professor I strive to give my students greatest possible exposure to many problems, therefore:

- There are about 100 problems listed in the lecture notes, some of which will be solved or discussed during the lectures.
- I do not commit to solve all of them but they represent absolute minimum!
- There are additional 60 problems to be discussed in DGDs with your TA
- There will be 2 tests in which you will be asked to solve about 14 MC problems and 10 long problems in total
- There will be 60 assignment problems for you to solve
- This will amount to about 250 problems solved in the course of the semester! ( not counting the quizzes etc.)
- There are about 80 online quiz questions I will ask of you.
- Also there are past midterms and past final exam for you to get use to the format and difficulty level of the tests.
- You may also use them as an evaluation tool before your tests.
- Any student who'll do (re-do) all of the above before the final will not be surprised by the exam!

### How much time will it all take?

Research indicates that what is needed is 2 to 3 hrs per one hour of in-class instruction/per week.

In other words to do well in this class ( B+ or better) one would need to put in 7 to 12 hrs of studying per week ( does not include the labs).

## CIVILITY AND RESPECT

### **1 Please be mindful of other students needs!**

Limit to minimum the disruptive behavior:

- Being late,
- Talking,
- Taking trips to the washroom.

Please switch off the phones and other electronic devices.

### **2 Rules regarding Food in the classroom**

As a general rule do not bring food to the class-room, please!

Food staples to be avoided in particular:

- Extremely hot coffee (safety!)
- Full 4-course breakfast!
- Loud crunchy food ( crackers, celeries and carrots, chips, plastic wrapped candy, popcorn)
- Aromatic food (pasta, oranges, nachos, pizza, onions, popcorn).

If you really have to have something to eat, I suggest soft-bread sandwich eaten discretely, somewhere in the back seats of the classroom.

## WHY DO WE NEED TO KNOW BASIC PHYSICS?

- 5 Educated people should know a little bit about everything. This includes physics.
- 4 Everyday practice of all of natural sciences requires using of the very advanced physical instruments.  
All natural sciences use physical methods and models.  
As a result of this, our understanding of physics will make us better biologists, chemists, geologists, and physicians.
- 3 Physics is the most fundamental knowledge about the material world. Laws of physics apply to every system.  
It means that on the most fundamental level, all of the natural sciences: chemistry, biology, geology, meteorology, medicine are in fact some form of physics.  
**ALL SCIENTISTS SHOULD KNOW PHYSICS AT SOME FUNDAMENTAL LEVEL.**
- 2 As science graduates, some of us might one day need to teach Physics to high-school students. It would be best if we were competent...
- 1 Physics is a fascinating subject worth knowing. (It is cool!)

This class focus is on the last two points:

- i) it should give you competence and confidence necessary to teach lower level physics in HS science classes
- ii) it should provide you with the basic idea of what real physics is all about

## **METASKILLS STUDENTS WILL LEARN IN THIS CLASS**

- 1 Problem Solving.
- 2 Analytical and Critical Thinking.
- 3 Self Confidence.
- 4 Discipline and Patience.
- 5 Determination in the Face of Adversity.

# HIGH SCHOOL MATHEMATICS EVERYBODY IS EXPECTED TO KNOW

This course requires certain mathematical proficiency. Below is a list of skills/ knowledge that we expect every student to possess to be successful in this class:

1. Solving linear equations
2. Solving quadratic equations
3. Solving systems of linear/quadratic equations
4. Trigonometry
5. Geometry
6. Vectors
7. Knowledge of all the fundamental functions and corresponding graphs:  
Linear quadratic polynomial trigonometric logarithmic, exponential.
8. Differential Calculus

At its end, the textbook contains appendices on the fundamental math. Please look them up! Also there is a whole chapter on vectors that will not be discussed in class (but it will be reviewed in the first DGD).

Make sure that you mastered this material ASAP.

It will make huge difference, as we will be using this simple math all the time.

Brief Mathematics Review is provided in your textbook on pages: A-4-A-19 (appendix B)

# INTRODUCTION TO THERMODYNAMICS

## WHAT IS THERMODYNAMICS?

State Variables

Macroscopic vs. Microscopic

0<sup>th</sup> Law of Thermodynamics

Temperature and Pressure

Thermal Expansion of Solids and Fluids

(Reading Assignment)

DEMO 1: Atmospheric Pressure: Pop Can

DEMO 2: Oil + water in the U-Tube

DEMO 3: Thermal Expansion of Solids

4 Quiz Questions

7 Suggested Problems

READING ASSIGNMENT: Chapter 19

# State Variables

## Macroscopic vs. Microscopic

A state variable is an element of the set of variables that describe the state of a dynamical system.

Temperature, pressure, internal energy, enthalpy, entropy are examples of state variables in a thermodynamics system.

These are macroscopic variables attributable to the large ensembles of atoms/molecules!

In case of simple mechanical systems: position coordinates and their derivatives are typical state variables.

These are microscopic variables attributable to single atoms/molecules!

ONE OF THE MAJOR ACCOMPLISHMENTS OF THE STATISTICAL MECHANICS WAS OBTAINING OF THE STATE VARIABLES FROM MICROSCOPIC VARIABLES DESCRIBING AVERAGE SINGLE MOLECULE!

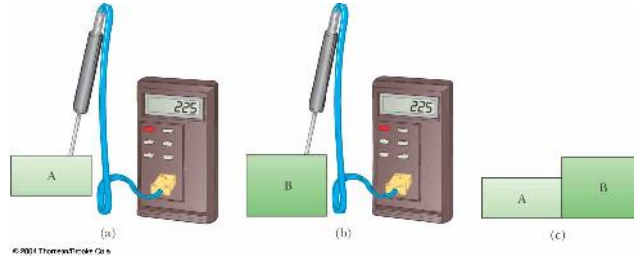
from  $(r, v)$  of single molecule  $\rightarrow$  to  $(p, T, E_{\text{int}}, S)$  of the whole gas

## • 0<sup>th</sup> Law of Thermodynamics

- If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other

- Object C (thermometer) is placed in contact with A until they achieve thermal equilibrium

- The reading on C is recorded



- Object C is then placed in contact with object B until they achieve thermal equilibrium
  - The reading on C is recorded again
  -
- If the two readings are the same, A and B are also in thermal equilibrium

- IF TWO OBJECTS ARE IN THERMAL EQUILIBRIUM THERE IS NO ENERGY TRANSFER BETWEEN THEM ( THEY HAVE THE SAME TEMPERATURE)

## Thermal Contact

- Two objects are in **thermal contact** with each other if energy can be exchanged between them
- The exchanges we will focus on will be in the form of heat or electromagnetic radiation
- The energy is exchanged due to a temperature difference

## Thermal Equilibrium

- Thermal equilibrium is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact
- The thermal contact does not have to also be physical contact

# TEMPERATURE

## Temperature

- Our senses provide us with a qualitative indication of temperature
- We associate the concept of temperature with how "hot" or "cold" an objects "feels."
- It is very primitive and inaccurate way to establish temperature
- compare the "feel" you get when touching wooden bar vs the feeling of the metal bar at the same temperature)
- **Our senses are unreliable for this purpose, so we need a technical definition of temperature!**
- **Temperature** can be thought of as the property that determines whether an object is in thermal equilibrium with other objects
- Two objects in thermal equilibrium with each other are at the same temperature
  - If two objects have different temperatures, they are not in thermal equilibrium with each other

## Thermometers

- Thermometer is a device used to measure the temperature of a system.
- In order to be effective thermometer needs to fulfill following general conditions
  - Thermometer needs to have some linearly temperature dependant physical parameter
  - **Needs to have small "heat capacity"**
  - (by introducing it into the system we will change the system temperature - we want that change to be negligible!)
- Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes.
- These properties include:
  - The volume of a liquid
  - The dimensions of a solid
  - The pressure of a gas at a constant volume
  - The volume of a gas at a constant pressure
  - The electric resistance of a conductor
  - The color of an object
- A temperature scale can be established on the basis of any of these physical properties
- A thermometer can be calibrated by placing it in contact with some natural systems that remain at constant temperature
- Common systems involve water.
- A mixture of ice and water at atmospheric pressure called the **ice point** of water.

## Liquid in glass Thermometers

- A common type of thermometer is a liquid-in-glass
- The material in the capillary tube expands as it is heated
- The liquid is usually mercury or alcohol
- Inaccurate far from the calibration points
- Useful only in the -30 to 80 C



## Thermocouple Thermometers

- Commonly used in variety of environments from low -250C to +1900C.
- Utilize the thermoelectric effect:
  - when conductor is subjected to a thermal gradient, it will generate a voltage.
- Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original.
- The magnitude of the effect depends on the metal in use.
- Using a different metal to complete the circuit creates a circuit in which the two legs generate different voltages, leaving a small difference in voltage available for measurement. That difference increases with temperature, and can typically be between 1 and 70 microvolts per degree Celsius ( $\mu V/^{\circ}C$ ) for the modern range of available metal combinations.
- Certain combinations have become popular as industry standards, driven by cost, availability, convenience, melting point, chemical properties, stability, and output. This coupling of two metals gives the thermocouple its name.



# TEMPERATURE SCALES

## Celsius Scale

- The ice point of water is defined to be 0° C
- The steam point of water is defined to be 100° C
- The length of the column between these two points is divided into 100 increments, called degrees

## Fahrenheit Scale

- A common scale in everyday use in the US
- Named for Daniel Fahrenheit
- Temperature of the ice point is 32 °F
- Temperature of the steam point is 212 °F
- There are 180 divisions (degrees) between the two reference points

## Kelvin (absolute) Scale

- Absolute zero is used as the basis of the absolute temperature scale
- The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale
- The absolute scale is also called the kelvin scale
- Named for William Thomson, Lord Kelvin
- The triple point temperature is 273.16 K
- No degree symbol is used with kelvins
- The kelvin is defined as 1/273.16 of the difference between absolute zero and the temperature of the triple point of water

## Conversions:

- Celsius and Kelvin have the same size degrees, but different starting points

$$T_C = T - 273.15$$

- Celsius and Fahrenheit have different sized degrees and different starting points

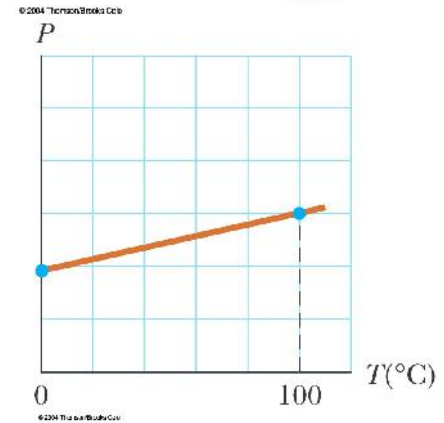
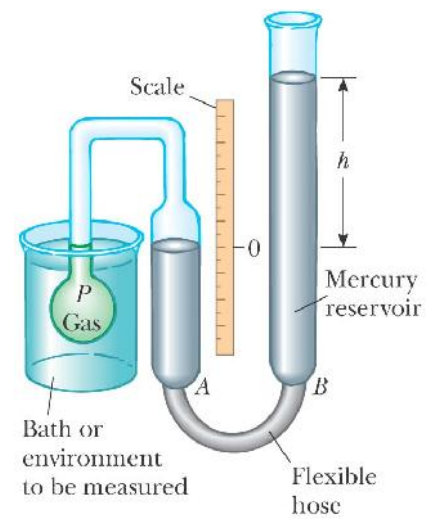
$$T_F = \frac{9}{5} T_C + 32$$

Ice point temperatures:  $0^\circ\text{C} = 273.15\text{ K} = 32^\circ\text{ F}$

Steam point temperatures:  $100^\circ\text{C} = 373.15\text{ K} = 212^\circ\text{ F}$

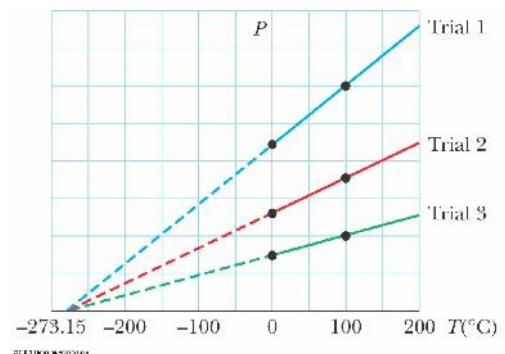
## Constant Volume Gas Thermometer

- The physical change exploited is the variation of pressure of a fixed volume gas as its temperature changes
- The volume of the gas is kept constant by raising or lowering the reservoir B to keep the mercury level at A constant
- The thermometer is calibrated by using a ice water bath and a steam water bath
- The pressures of the mercury under each situation are recorded
  - The volume is kept constant by adjusting A
- The information is plotted
- To find the temperature of a substance, the gas flask is placed in thermal contact with the substance
- The pressure is found on the graph
- The temperature is read from the graph



## Absolute Zero

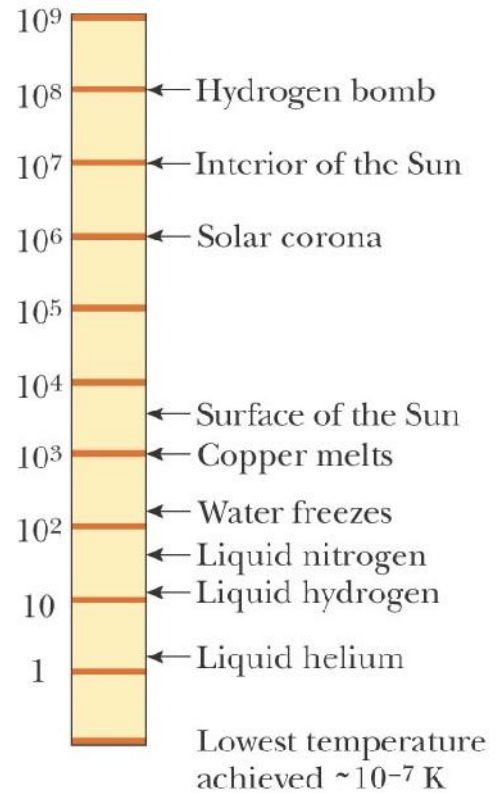
- The thermometer readings are virtually independent of the gas used
- If the lines for various gases are extended, the pressure is always zero when the temperature is
- $-273.15^\circ\text{C}$
- This temperature is called **absolute zero**
- The absolute temperature scale is now based on two new fixed points (adopted by in 1954 by the International Committee on Weights and Measures)
  - One point is absolute zero
  - The other point is the triple point of water
- This is the combination of temperature and pressure where ice, water, and steam can all coexist
- The triple point of water occurs at  $0.01^\circ\text{C}$  and 4.58 mm of mercury
- This temperature was set to be 273.16 on the absolute temperature scale
  - This made the old absolute scale agree closely with the new one
  - The units of the absolute scale are **kelvins**
- The figure at right gives some absolute temperatures at which various physical processes occur
- The scale is logarithmic
- The temperature of absolute zero cannot be achieved
  - Experiments have come as close to it as the Quantum Mechanics allows (few pK /  $\text{pK}=10^{-12}\text{K}$ )



## Energy at Absolute Zero

- According to classical physics, the kinetic energy of the gas molecules would become zero at absolute zero
- The molecular motion would cease
  - Therefore, the molecules would settle out on the bottom of the container
- Quantum theory modifies this and shows some residual energy would remain
  - This energy is called the **zero-point** energy

Temperature (K)



© 2004 Thomson/Brooks Cole

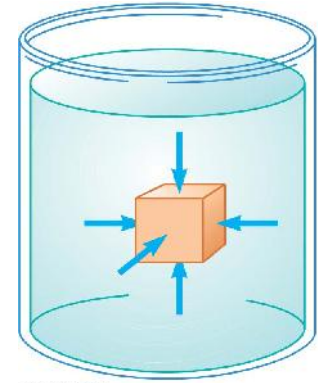
BIG QUESTION :

How does one measure  $T=10^6$  K or higher?

# PRESSURE

- The **pressure**  $P$  of the fluid at the level to which the device has been submerged is the ratio of the force to the area

$$p = \frac{F}{A}$$



- Pressure is a scalar quantity
  - Because it is proportional to the magnitude of the force
- Unit of pressure is **pascal** (Pa)

$$1\text{Pa} = \frac{1\text{N}}{1\text{m}^2}$$

Pressure in the uniform static fluid is constant at the same level

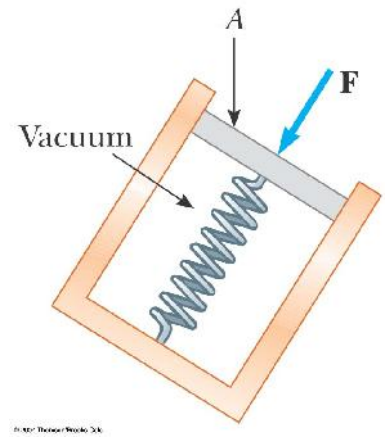
The pressure  $p$  at a depth  $h$  below a point in the liquid at which the pressure is  $p_0$  is greater by an amount  $\rho gh$ .

$$p = p_0 + \rho gh$$

- The liquid has a density of  $\rho$ . We assume the density is the same throughout the fluid.
- If the liquid is open to the atmosphere, and  $P_0$  is the pressure at the surface of the liquid, then  $P_0$  is *atmospheric pressure*
- $P_0 = 1.00 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$

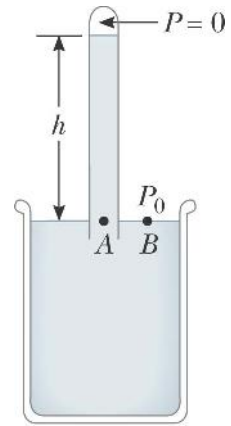
## Measuring Pressure

- The spring is calibrated by a known force
- The force due to the fluid presses on the top of the piston and compresses the spring
- The force the fluid exerts on the piston is then measured



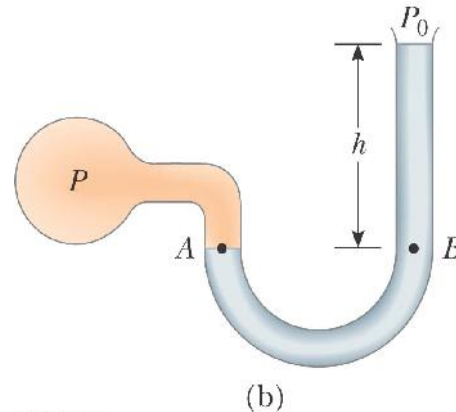
## Barometer

- Invented by Torricelli
- A long closed tube is filled with mercury and inverted in a dish of mercury
  - The closed end is nearly a vacuum
- Measures atmospheric pressure as
- One 1 atm = 0.760 m (of Hg)



## Manometer

- A device for measuring the pressure of a gas contained in a vessel
- One end of the U-shaped tube is open to the atmosphere
- The other end is connected to the pressure to be measured
- Pressure at B is  $P_0 + gh$
- $P = P_0 + gh$
- P is the **absolute pressure**
- The **gauge pressure** is  $P - P_0$ 
  - This is also  $gh$
  - This is what you measure in your tires



## IMPORTANT QUESTIONS:

- 1 What is the total force acting on human body associated with the atmospheric pressure?
- 2 What is the origin of atmospheric pressure?

# THERMAL EXPANSION OF SOLIDES AND LIQUIDS: READING ASSIGNMENT

Length:

$$\Delta L = (L_f - L_i) = \alpha L_i (T_f - T_i) = \alpha L_i \Delta T$$

Volume:

$$\Delta V = (V_f - V_i) = \beta V_i (V_f - V_i) = \beta V_i \Delta T$$

Area:

$$\Delta S = (S_f - S_i) = \chi S_i (S_f - S_i) = \chi S_i \Delta T$$

Read the relevant material in the textbook

Find out the meaning of all the equations and variables above

Answer the following questions:

- 1 How do (linear expansion coefficient) and (average coefficient of volume expansion) relate to each other?
- 2 How do (linear expansion coefficient) and (average coefficient of area expansion) relate to each other?

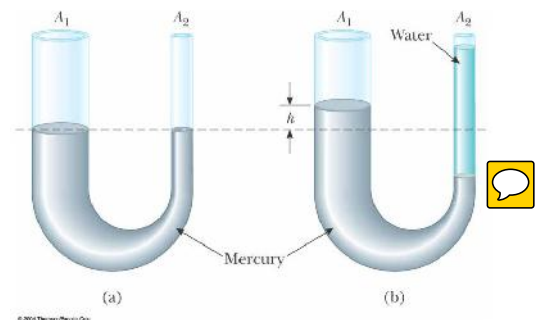
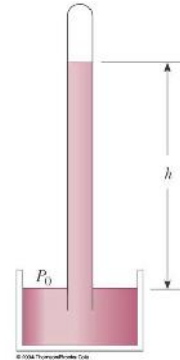
# SUGGESTED PROBLEMS

## Temperature Scales

- At what absolute temperature the temperatures measured using Celsius scale and Fahrenheit Scale are equal?
- On a Strange temperature scale, the freezing point of water is  $-15.0^{\circ}\text{S}$  and the boiling point is  $+60.0^{\circ}\text{S}$ . Develop a *linear* conversion equation between this temperature scale and the Celsius scale. **2S\_JS\_E 6**

## Pressure:

- Blaise Pascal duplicated Torricelli's barometer using a red Bordeaux wine, of density  $984\text{ kg/m}^3$ , as the working liquid (Fig. P14.17). What was the height  $h$  of the wine column for normal atmospheric pressure? Would you expect the vacuum above the column to be as good as for mercury?
- Mercury is poured into a U-tube as in Figure P14.18a. The left arm of the tube has cross-sectional area  $A_1$  of  $10.0\text{ cm}^2$ , and the right arm has a cross-sectional area  $A_2$  of  $5.00\text{ cm}^2$ . One hundred grams of water are then poured into the right arm as in Figure
  - Determine the length of the water column in the right arm of the U-tube.
  - Given that the density of mercury is  $13.6\text{ g/cm}^3$ , what distance  $h$  does the mercury rise in the left arm?



## Change of length with temperature

- A certain telescope forms an image of part of a cluster of stars on a square silicon charge-coupled detector (CCD) chip  $2.00\text{ cm}$  on each side. A star field is focused on the CCD when it is first turned on and its temperature is  $20.0^{\circ}\text{C}$ . The star field contains  $5\,342$  stars scattered uniformly. To make the detector more sensitive, it is cooled to  $-100^{\circ}\text{C}$ . How many star images then fit onto the chip? The average coefficient of linear expansion of silicon is  $4.68 \times 10^{-6}\text{ (}^{\circ}\text{C)}^{-1}$ .
- A copper wire and a lead wire are joined together, end to end. The compound wire has an effective coefficient of linear expansion of  $20.0 \times 10^{-6}\text{ (}^{\circ}\text{C)}^{-1}$ . What fraction of the length of the compound wire is copper?
- A steel rod undergoes a stretching force of  $500\text{ N}$ . Its cross-sectional area is  $2.00\text{ cm}^2$ . Find the change in temperature that would elongate the rod by the same amount as the  $500\text{-N}$  force does. Consult the tables for proper values of expansion coefficients.

# IDEAL GAS LAW

What is the ideal gas?

Ideal Gas Law

pV Diagrams for Ideal Gas

pV Diagrams for Various Gas Transformations

DEMO 1: Atmospheric Pressure: Can

DEMO 2: Liquid Nitrogen + Helium filled balloon.

SECOND INTERLUDE:

SERIES: 1 FUNDAMENTAL PRINCIPLES OF NATURE:  
STRUCTURE OF UNIVERSE

4 Quiz Questions

8 Suggested Problems

READING ASSIGNMENT: Chapter19

# IDEAL GAS

- An ideal gas is a theoretical gas composed of a set of randomly-moving point particles that interact only through elastic collisions.
- The ideal gas concept is useful because it obeys the ideal gas law, a simplified equation of state, and it yields to analysis under statistical mechanics.
- It is a gas in which the interatomic forces within the gas are very weak
  - We can imagine these forces to be nonexistent
- Note that there is no equilibrium separation for the atoms
  - Thus, no "standard" volume at a given temperature
  - For a gas, the volume is entirely determined by the container holding the gas
- Equations involving gases will contain the volume,  $V$ , as a variable

## Equation of State

- It is useful to know how the volume, pressure and temperature of the gas of mass  $m$  are related
- The equation that interrelates these quantities is called the **equation of state**
  - These are generally quite complicated
  - If the gas is maintained at a low pressure, the equation of state becomes much easier
  - This type of a low density gas is commonly referred to as an **ideal gas**

## Gas Laws

- When a gas is kept at a constant temperature, its pressure is inversely proportional to its volume (Boyle's law)
- When a gas is kept at a constant pressure, its volume is directly proportional to its temperature (Charles and Gay-Lussac's law)

## Ideal Gas Law

- The equation of state for an ideal gas combines and summarizes the other gas laws

$$PV=nRT$$

This is known as the **ideal gas law**

- $P$  pressure
- $V$  volume
- $n$  number of moles of substance  $n=N/N_A$
- $T$  temperature
- $R$  is a constant, called the Universal Gas Constant
- $R = 8.314 \text{ J/mol} \cdot \text{K} = 0.08214 \text{ L} \cdot \text{atm/mol} \cdot \text{K}$
- From this, you can determine that 1 mole of any gas at atmospheric pressure and at  $0^\circ \text{C}$  is taking
- 
- 22.4 liters of volume.

## The Mole

- The amount of gas in a given volume is conveniently expressed in terms of the number of moles
- One **mole** of any substance is that amount of the substance that contains **Avogadro's number** of constituent particles
  - Avogadro's number  $N_A = 6.022 \times 10^{23}$
  - The constituent particles can be atoms or molecules
- The number of moles can be determined from the mass of the substance:  $n = m / M$ 
  - $M$  is the molar mass of the substance
  - $m$  is the mass of the sample
  - $n$  is the number of moles

## IDEAL GAS EQUATION IN ALTERNATIVE FORM

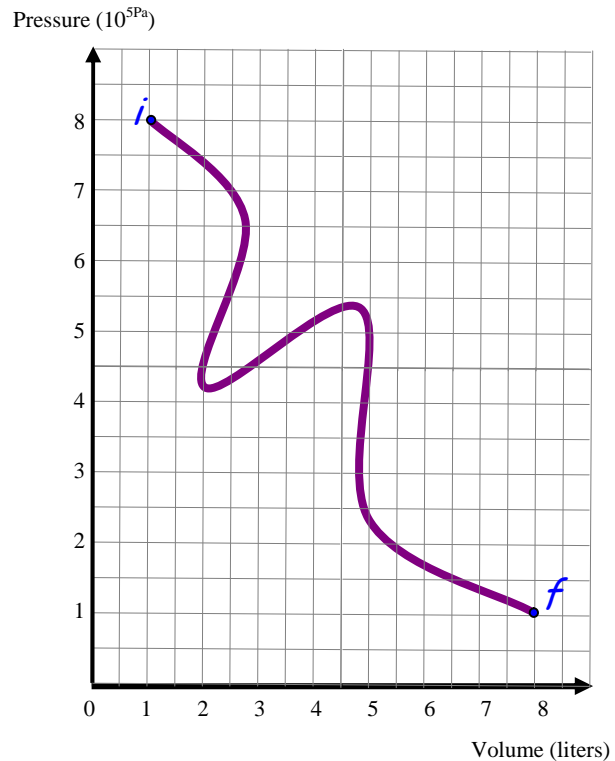
- The ideal gas law is often expressed in terms of the total number of molecules,  $N$ , present in the sample:


$$PV = nRT = (N/N_A) RT = Nk_B T$$

- $k_B$  is Boltzmann's constant
- $k_B = 1.38 \times 10^{-23} \text{ J/K}$
- It is common to call  $P$ ,  $V$ , and  $T$  the **thermodynamic variables** of an ideal gas

# Phase Space and PV Diagrams

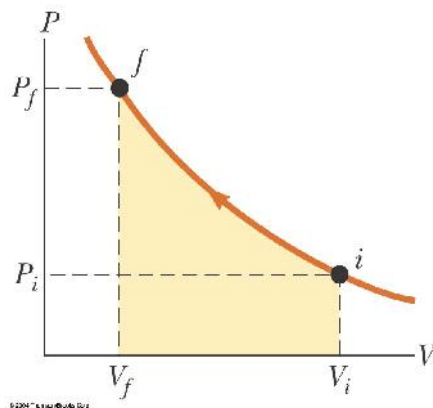
- If the system has well-defined Pressure, Volume and Temperature, we are able to represent its state at every moment in time as a point on a P-V, P-T or V-T diagram.
- The change of these parameters corresponds to the change of the coordinates in such "phase space diagram"
- PV diagram is used when the pressure and volume are known at each step of the process.
- The state of the gas at each step can be plotted on a graph called a **PV diagram**
  - This allows us to visualize the process through which the gas is progressing
- The curve is called the *path*



Pressure-volume diagram is used to describe a thermal cycle involving the following two variables:  
 Volume (on the X axis) Pressure (on the Y axis)

This is in fact enough information to fully describe a simple system from a thermodynamic standpoint. Each point on the diagram has coordinates  $(V, p)$  which fully describe the ideal gas system at any point of time.

The diagrams are useful when one wants to calculate the work done by the system, the integral of the pressure with respect to volume. One can often quickly calculate this using the PV diagram as it is simply the area enclosed by the cycle.



# Suggested Problems:

## Ideal Gas Equation

- 1 Show that 1 mole of any gas at atmospheric pressure and at  $0^\circ\text{C}$  is taking 22.4 liters of volume
- 2 100 grams of oxygen and 100 grams of hydrogen gas occupy separate, equal sections of 200 liter tank. The divide is removed and the gases are allowed to mix and react with each other. The temperature is kept constant at  $110^\circ\text{C}$ , throughout the process
  - a) find the pressure of each gas in the separate containers
  - b) find the pressure after the reaction ends.
- 3 A popular brand of cola contains 6.50 g of carbon dioxide dissolved in 1.00 L of soft drink. If the evaporating carbon dioxide is trapped in a cylinder at 1.00 atm and  $20.0^\circ\text{C}$ , what volume does the gas occupy?
- 4 The mass of a hot-air balloon and its cargo (not including the air inside) is 200 kg. The air outside is at  $10.0^\circ\text{C}$  and 101 kPa. The volume of the balloon is  $400\text{ m}^3$ . To what temperature must the air in the balloon be heated before the balloon will lift off? (Air density at  $10.0^\circ\text{C}$  is  $1.25\text{ kg/m}^3$ .)
- 5 Just 9.00 g of water is placed in a 2.00-L pressure cooker and heated to  $500^\circ\text{C}$ . What is the pressure inside the container?
- 6 A tank having a volume of  $0.100\text{ m}^3$  contains helium gas at 150 atm. How many balloons can the tank blow up if each filled balloon is a sphere 0.300 m in diameter at an absolute pressure of 1.20 atm?
- 7 At 25.0 m below the surface of the sea ( $\rho = 1\,025\text{ kg/m}^3$ ), where the temperature is  $5.00^\circ\text{C}$ , a diver exhales an air bubble having a volume of  $1.00\text{ cm}^3$ . If the surface temperature of the sea is  $20.0^\circ\text{C}$ , what is the volume of the bubble just before it breaks the surface?
- 8 Long-term space missions require reclamation of the oxygen in the carbon dioxide exhaled by the crew. In one method of reclamation, 1.00 mol of carbon dioxide produces 1.00 mol of oxygen and 1.00 mol of methane as a byproduct. The methane is stored in a tank under pressure and is available to control the attitude of the spacecraft by controlled venting. A single astronaut exhales 1.09 kg of carbon dioxide each day. If the methane generated in the respiration recycling of three astronauts during one week of flight is stored in an originally empty 150-L tank at  $-45.0^\circ\text{C}$ , what is the final pressure in the tank?

# FIRST LAW OF THERMODYNAMICS

Work  
Heat  
Internal Energy  
Conservation Of Energy  
First Law of Thermodynamics

DEMO 1 Heating of the drill

DEMO 2 Heat -work equivalence experiment

2 quiz questions

4 Suggested Problems

READING ASSIGNMENT: Chapter 20

## CONSERVATION OF MECHANICAL ENERGY

If we dealing with a system that conserves Mechanical Energy (Which means that there are no losses) We can state the

The Law of Conservation of Mechanical Energy:

in the absence of losses the Total Mechanical Energy of the system is constant.

The only two forms of Mechanical Energy available to macroscopic bodies are Potential Energy(U) and Kinetic Energy (K)

Thus we can state our Conservation Law in the following form:

$$K+U=E=const$$

## WORK in MECHANICS

Work is an energy transfer associated with the change of mechanical energy.

For simple body work is defined as product of acting Force and displacement of that body.

$$dW = Fdx$$

Work = Change in Mechanical Energy

$$W = K + U$$

Everyday experience makes us aware of unavoidable nature of losses.

Effects such as: friction, drag, viscosity dissipate energy and diminish amount of mechanical energy of the system, eventually bringing all motion to a stop.

The loss of mechanical energy is accounted for if one adds heat and the increase of the system's internal energy to the balance.

We will now find out more about these Heat and Internal Energy

## HEAT:

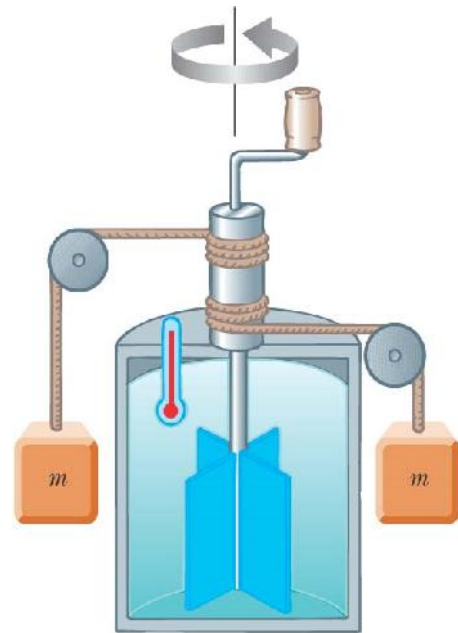
- **Heat** is a byproduct of friction. Whenever the Kinetic Energy is lost due to friction losses we will observe the system and the surroundings to "heat up."
- 
- **Heat** is defined as the transfer of energy across the boundary of a system due to a temperature difference between the system and its surroundings.
- The term *heat* will also be used to represent the *amount* of energy transferred by this method

## INTERNAL ENERGY

- **Internal energy** is all the energy of a system that is associated with its internal structure (its microscopic components).
- **Today we know that on fundamental level these components are its atoms and molecules.**
- **The system is viewed from a reference frame at rest with respect to the center of mass of the system.**
- **The kinetic energy due to its motion through space is **not** included.**
- Internal energy does include kinetic energies due to:
  - Random translational motion
  - Rotational motion
  - Vibrational motion
- Internal energy also includes potential energy between molecules.

# Mechanical Equivalent of Heat

- Joule established the equivalence between mechanical energy and internal energy
- His experimental setup is shown at right
- The loss in potential energy associated with the blocks equals the work done by the paddle wheel on the water.
- Joule found that it took approximately 4.18 J of mechanical energy to raise temperature of 1g of water by 1°C.
- Later, more precise, measurements determined the amount of mechanical energy needed to raise the temperature of 1g of water from 14.5°C to 15.5°C
- 1 cal = 4.186 J
  - This is known as the **mechanical equivalent of heat**
  - The "Calorie" used for food is actually 1 kilocalorie
- In the US Customary system, the unit is a BTU (British Thermal Unit)



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- One BTU is the amount of energy transfer necessary to raise the temperature of 1 lb of water from 63oF to 64oF
- The standard in the text is to use Joules
- Thermodynamics and mechanics were considered to be separate branches
  - Until about 1850
  - Experiments by James Joule and others showed a connection between them
- A connection was found between the transfer of energy by **heat** in thermal processes and the transfer of energy by **work** in mechanical processes
- The concept of energy was generalized to include internal energy
- The Law of Conservation of Energy emerged as a universal law of nature

# The Law of Conservation of Energy

In the isolated system the total energy (sum of all forms of energy) is constant

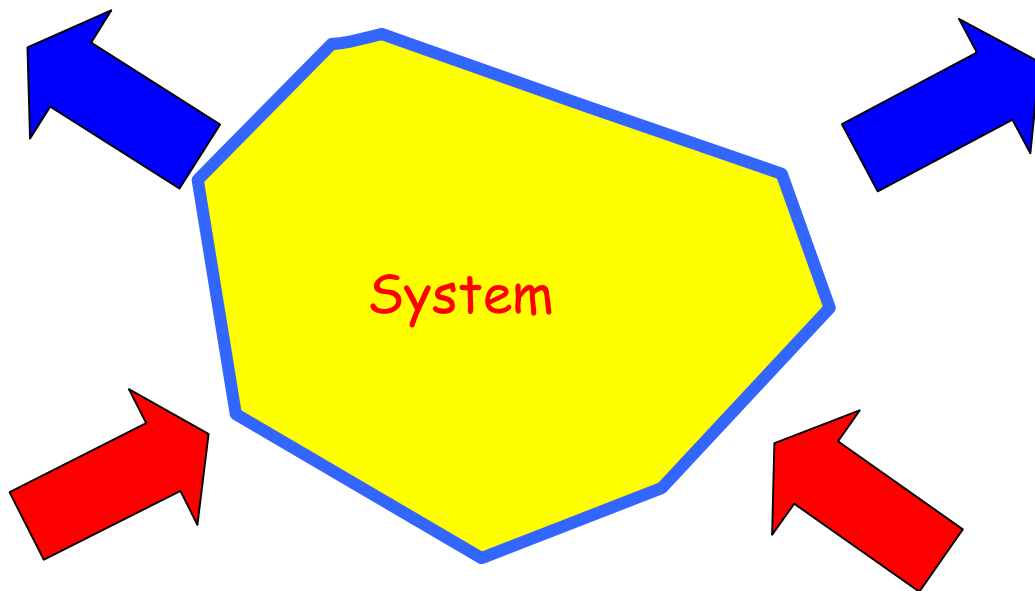
## The First Law of Thermodynamics:

Expresses the conservation of energy for thermodynamic systems.  
Change of the Internal Energy( $E_{int}$ ) is due to two transfer mechanisms:  
Heat( $Q$ ) and Work ( $W$ )

$$E_{int} = W + Q$$

Work transferred  
out of the system

Heat transferred  
out of the system



Heat transferred  
into the system

Work transferred  
into the system

$$E_{int} = W + Q$$

# First Law of Thermodynamics in Differential Form:

For small incremental quasi-static transfer

$$dE_{\text{int}} = dQ + dW$$

NOTE:

First law in its differential form is very useful in obtaining of the thermodynamic relations.

We will use it a lot in this course!

## UNITS of ENERGY HEAT AND WORK

SI unit of energy is Joule:

$$1\text{J} = 1\text{Nm} \text{ (Newton times meter)}$$

Heat and work are measured using the same units as energy

Other important and widely used energy units are:

$$1\text{Btu} = 1054\text{J}$$

Calorie-cal - used in thermodynamics, chemistry and biomechanics

Electron Volt - eV - used in quantum physics and chemistry, spectroscopy

Wavenumber - $\text{cm}^{-1}$ -(reciprocal centimeter) used in widely in spectroscopy

## HOMEWORK:

Fill the conversion table below

	J	cal	eV	cm <sup>-1</sup>
J	1			
cal	4.186	1		
eV	$1.6 \times 10^{-19}$		1	
cm <sup>-1</sup>				1

$$1 \text{ cal} = 4.186 \text{ J}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

## Suggested Problems:

Note : some of the problems below may require violation of the II law of thermodynamics

- 1 The system performed 70J of work on the outside environment while receiving the 80J of heat from it and expelling 20J of heat. What is the net change of the internal energy of the system?
- 2 The thermal engine (system operating in a cyclic fashion) performs 150 J of work while receiving 500 J of heat from heat reservoir. How much heat does the engine expel to the cold reservoir?
- 3 One liter cylinder contains 1 mole of the ideal gas molecules having the average kinetic energy of 0.1eV. What is the total internal energy of this gas?
- 4 1 mole of ideal gas has total internal energy of 200J. What is the average kinetic energy (in eV) of one molecule of this gas?

# HEAT

Heat

Specific Heats and Molar Specific Heats

Phase Changes and Latent Heat

Calorimetry

Adiabatic Process in the Ideal Gas

Heat Transfer Mechanisms

Demo 1: Calorimetric Measurements

Demo 2: Radiation Convection and Conductance

Demo 3: Radiating Bodies

12 Suggested Problems

READING ASSIGNMENT: chapter20

- **Heat** is defined as the transfer of energy across the boundary of a system due to a temperature difference between the system and its surroundings
- The term *heat* will also be used to represent the *amount* of energy transferred by this method
- Historically, the **calorie** was the unit used for heat
  - One calorie is the amount of energy transfer necessary to raise the temperature of 1 g of water from 14.5°C to 15.5°C
    - The "Calorie" used for food is actually 1 kilocalorie
- In the US Customary system, the unit is a BTU (British Thermal Unit)
  - One BTU is the amount of energy transfer necessary to raise the temperature of 1 lb of water from 63°F to 64°F
- The standard in the text is to use Joules

# The Heat Capacities and Specific Heats

Various bodies require different amounts of energy to be heated by the same temperature difference. Heat capacity reports on that property of the body .

- The **heat capacity**,  $C$ , of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by  $1^\circ\text{C}$
- If energy  $Q$  produces a change of temperature of  $\Delta T$ , then

$$Q = c \Delta T$$

## Specific Heat

- **Specific heat**,  $c$ , is the heat capacity per unit mass
- If energy  $Q$  transfers to a sample of a substance of mass  $m$  and the temperature changes by  $\Delta T$ , then the specific heat is
- The specific heat is essentially a measure of how insensitive a substance is to the addition of energy
  - The greater the substance's specific heat, the more energy that must be added to cause a particular temperature change
- The equation is often written in terms of  $Q$ :

$$Q = m c \Delta T$$

## Specific Heat versus Molar Specific Heat

$Q = m c \Delta T$	specific heat expression ( $m$ = mass in kg) $c$ = specific heat
$Q = N m_1 c \Delta T$	mass = $N$ ( the number of molecules) $\times m_1$ ( mass of a single molecule)
$Q = \frac{N_A}{N_A} N m_1 c \Delta T$	I am allowed to multiply any expression by $(1 = \frac{N_A}{N_A})$
$Q = \frac{N}{N_A} N_A m_1 c \Delta T$	I am allowed to change the order of multiplication
$Q = \left( \frac{N}{N_A} \right) (N_A m_1) c \Delta T$	I am allowed to group products in brackets
$Q = n M c \Delta T$	I am using $n = \frac{N_A}{N_A}$ ( number of moles) and $M = N_A m_1$ (molar mass)
$Q = n C \Delta T$	specific molar heat expression ( $n$ amount of substance in moles) $C = M c$ is a molar specific heat of the substance

$$Q = n C \Delta T$$



this expression is very useful in discussion of the ideal gas thermodynamics

# Molar Specific Heat of Gases

It has been found experimentally that during the isobaric and isovolumetric gas transitions two gases exhibit two different molar heat capacities  $C_p$  and  $C_v$

Consequently two different expressions for heat need to be used in these transitions

$$Q = nC_v \Delta T \text{ when } V = \text{const.}$$

$$Q = nC_p \Delta T \text{ when } p = \text{const.}$$

## $Q = mc \Delta T$ SIGN CONVENTION

- If the temperature increases:  
 $Q$  and  $T$  are positive  
Energy transfers into the system
- If the temperature decreases:  
 $Q$  and  $T$  are negative  
Energy transfers out of the system

## Specific Heat Variation with Temperature

- Technically, the specific heat varies with temperature
- The corrected equation is  $Q = m \int_{T_i}^{T_f} c dT$
- However, if the temperature intervals are not too large, the variation can be ignored and  $c$  can be treated as a constant  
For most substances there is only about a 1% variation between  $0^\circ$  and  $100^\circ\text{C}$

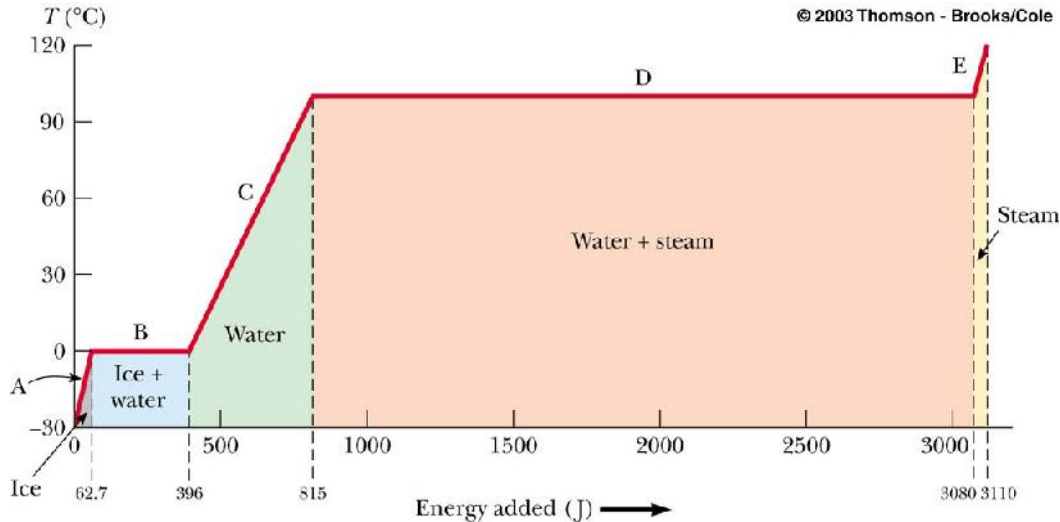
## Specific Heat of Water

- Water has the highest specific heat of common materials
- This is responsible for many weather phenomena
  - Moderate temperatures near large bodies of water
  - Global wind systems
  - Land and sea breezes

# Phase Changes and Latent Heats of Transformation

- A phase change is when a substance changes from one form to another
  - Two common phase changes are
    - Solid to liquid (melting)
    - Liquid to gas (boiling)
- During a phase change, there is no change in temperature of the substance
- Different substances react differently to the energy added or removed during a phase change
  - Due to their different molecular arrangements
- The amount of energy also depends on the mass of the sample
- If an amount of energy  $Q$  is required to change the phase of a sample of mass  $m$ ,
- $L = Q / m$
- The quantity  $L$  is called the **latent heat** of the material
  - Latent means "hidden"
  - The value of  $L$  depends on the substance as well as the actual phase change
- The energy required to change the phase is  $Q = \pm mL$
  
- The *latent heat of fusion* is used when the phase change is from solid to liquid
- The *latent heat of vaporization* is used when the phase change is from liquid to gas
- The positive sign is used when the energy is transferred into the system
  - This will result in melting or boiling
- The negative sign is used when energy is transferred out of the system
  - This will result in freezing or condensation

# Graph of Ice to Steam



**How much energy is needed to convert one gram of ice at  $-30.0^{\circ}\text{C}$  to 1g of steam at  $120^{\circ}\text{C}$ ?**

Part A ( Warming up the Ice)

- During phase A, the temperature of the ice changes from  $-30.0^{\circ}\text{C}$  to  $0^{\circ}\text{C}$
- Use  $Q = m_i c_i T$  In this case, 62.7 J of energy are added

Part B (Melting: Phase change )

- Once at  $0^{\circ}\text{C}$ , the phase change (melting) starts
- The temperature stays the same although energy is still being added
- Use  $Q = m_i L_f$ 
  - The energy required is 333 J the total energy moves from 62.7 J to 396 J

Part C (Warming up the water )

- Between  $0^{\circ}\text{C}$  and  $100^{\circ}\text{C}$ , the material is liquid and no phase changes take place
- Energy added increases the temperature
- Use  $Q = m_w c_w T$ 
  - 419 J are added The total is now 815 J

Part D- Boiling (phase change)

- At  $100^{\circ}\text{C}$ , a phase change occurs (boiling)
- Temperature does not change
- Use  $Q = m_w L_v$ 
  - This requires 2260 J The total is now 3070 J

Part E- Warming up the steam

- After all the water is converted to steam, the steam will heat up
- No phase change occurs
- The added energy goes to increasing the temperature
- Use  $Q = m_s c_s T$ 
  - In this case, 40.2 J are needed
  - The temperature is going to  $120^{\circ}\text{C}$  The total is now 3110 J

# Molecular View of Phase Changes

Phase changes can be described in terms of the rearrangement of molecules (or atoms in an elemental substance)

- Liquid to Gas phase change
  - Molecules in a liquid are close together
  - The forces between them are stronger than those in a gas
  - Work must be done to separate the molecules
  - The latent heat of vaporization is the energy per unit mass needed to accomplish this separation
- Solid to Liquid phase change
  - The addition of energy will cause the amplitude of the vibration of the molecules about their equilibrium position to increase
  - At the melting point, the amplitude is great enough to break apart bonds between the molecules
  - The molecules can move to new positions
  - The molecules in the liquid are bound together less strongly than those of the solid
  - The latent heat of fusion is the energy per unit mass required to go from the solid-type to the liquid-type bonds
- The latent heat of vaporization is greater than the latent heat of fusion
  - In the liquid-to-gas phase change, the liquid-type bonds are broken
  - The gas molecules are essentially not bonded to each other
- It takes more energy to completely break the bonds than to change the type of bonds

## Calorimetry

- The technique for measuring specific heat involves heating a material, adding it to a sample of water, and recording the final temperature is known as **calorimetry**,
- A calorimeter is a device in which this energy transfer takes place
- The system of the sample and the water is isolated
- Conservation of energy requires that the amount of energy that leaves the sample equals the amount of energy that enters the water
  - Conservation of Energy Gives a Mathematical Expression of This:

$$Q_{\text{cold}} = -Q_{\text{hot}}$$

The negative sign in the equation is critical for consistency with the established sign convention  
Since each  $Q = mc\Delta T$ ,  $c_{\text{sample}}$  can be found by:

$$c_s = \frac{m_w c_w (T_f - T_w)}{m_s (T_s - T_f)}$$

- technically, the mass of the container should be included, but if  $m_w \gg m_{\text{container}}$  it can be neglected

## Adiabatic Process in the Ideal Gas

We are ready to discuss the last important process of ideal gas.

Adiabatic Process Is the process in which no heat is exchanged with the surroundings!

It may be proven that in such process

$$pV = \text{const where } \gamma > 1$$

We will demonstrate this in the course of the class.

## Heat Transfer Mechanisms: Reading Assignment (Self study!)

### Thermal Conduction:

Energy transfer by the heat ( on microscopic level it is caused by the exchange of kinetic energies of molecules of two bodies in thermal contact)

$$P = kA \frac{dT}{dx}$$

### Radiation:

energy transfer by the electromagnetic radiation emitted from the body

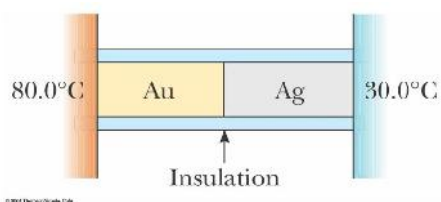
$$P = \sigma A e T^4$$

### Convection:

energy transfer by the movement of high T substance into low T substance. Takes form of convection currents.

## Suggested Problems:

- 1 A 2.5 kg aluminum is heated to  $92^{\circ}\text{C}$  and then dropped into 8 kg of water at  $5^{\circ}\text{C}$ . Assuming that water metal system is thermally isolated what is the system equilibrium temperature?
- 2 A 20g copper calorimeter contains 100g of water at  $30^{\circ}\text{C}$ . Into this is poured a 40 g of glass beads which have been heated to a temperature of  $100^{\circ}\text{C}$ . The final equilibrium temperature of the whole system is  $40^{\circ}\text{C}$ . What is the specific heat for the glass?
- 3 A water heater is operated by solar power. If solar collector has an area of  $6.00\text{m}^2$ , and the Intensity delivered by sunlight is  $550\text{W}/\text{m}^2$ , how long does it take to increase the temperature of  $1\text{m}^3$  of water from  $20^{\circ}\text{C}$  to  $60^{\circ}\text{C}$ ?
- 4 A 1kg of ice at  $-30^{\circ}\text{C}$  is added to 10 kg of steam at  $500^{\circ}\text{C}$ . answer the following questions:
  - a) What is the phase of the system of ice + steam if no heat escaped from it.
  - b) What is the final temperature when the equilibrium is established
- 5 A 5g lead bullet travelling with  $v=1200\text{m}/\text{s}$  embeds in the 1kg block of ice at  $(-1^{\circ}\text{C})$ . Knowing that practically all of the kinetic energy of the bullet is converted to heat find the final temperature of the bullet + ice system. How much water was produced during the melting?
- 6 Two speeding lead bullets each of mass 5 g and temperature of  $20^{\circ}\text{C}$  collide head on at speeds of  $500\text{m}/\text{s}$  each. Assuming a perfectly inelastic collision and no loss of energy to the atmospheres, describe the final state of the two bullet system.
7. The *Nova* laser at Lawrence Livermore National Laboratory in California is used in studies of initiating controlled nuclear fusion (Section 45.4). It can deliver a power of  $1.60 \times 10^{13}\text{ W}$  over a time interval of 2.50 ns. Compare its energy output in one such time interval to the energy required to make a pot of tea by warming 0.800 kg of water from  $20.0^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ .
8. A combination of 0.250 kg of water at  $20.0^{\circ}\text{C}$ , 0.400 kg of aluminum at  $26.0^{\circ}\text{C}$ , and 0.100 kg of copper at  $100^{\circ}\text{C}$  is mixed in an insulated container and allowed to come to thermal equilibrium. Ignore any energy transfer to or from the container and determine the final temperature of the mixture.
- 9 A bar of gold is in thermal contact with a bar of silver of the same length and area (Fig.). One end of the compound bar is maintained at  $80.0^{\circ}\text{C}$  while the opposite end is at  $30.0^{\circ}\text{C}$ . When the energy transfer reaches steady state, what is the temperature at the junction?
 


- 10 A glass window pane has an area of  $3.00\text{ m}^2$  and a thickness of 0.600 cm. If the temperature difference between its faces is  $25.0^{\circ}\text{C}$ , what is the rate of energy transfer by conduction through the window.
11. The surface of the Sun has a temperature of about 5 800 K. Radius of the Sun is  $6.96 \times 10^8\text{ m}$ . Calculate the total energy radiated by the Sun each second. Assume that the emissivity is 0.965.
- 12 The tungsten filament of a certain 100-W light bulb radiates 2.00 W of light. (The other 98 W is carried away by convection and conduction.) The filament has a surface area of  $0.250\text{ mm}^2$  and an emissivity of 0.950. Find the filament's temperature. (The melting point of tungsten is 3 683 K.)