# CH365 Chemical Engineering Thermodynamics

## Lesson 1
## Introduction and Fundamentals 1

Professor Andrew Biaglow
15 August 2022

https://usarmywestpoint.sharepoint.com/sites/cls.ch365/MainPage/default.aspx

# Classroom and Computer Etiquette

The following items are disruptive and can result in a COR or other disciplinary action:

- Working on assignments for other classes.

- Printing documents while I am speaking.

- Consuming food of any kind in the classroom.

- Chewing gum.

- Sleeping during class.

- Failure to sign out of computers.

- Not having a textbook.

If you see a computer floor plate open, please replace it.

If you print a document, please either collect it or cancel the print job.

Please bring any printer issues to the attention of your instructor.

Please sign out of lab computers (use Ctrl-Alt-Del to sign out).

# USMA Chemical Engineering Mission

To prepare commissioned leaders of character who are proficient in applying chemical and engineering principles to solve problems in a complex operational environment.

Published in the USMA Redbook (Part 2 – Disciplinary Offerings)

# Chemical Engineering Program Educational Objectives

During a career as commissioned officers in the United States Army and beyond, program graduates:

- Demonstrate effective leadership and chemical engineering expertise.

- Contribute to the solution of infrastructure or operational problems (in a complex operational environment).

- Succeed in graduate school or other advanced study programs.

- Advance their careers through clear and precise technical communication.

Published in the USMA Redbook (Part 2 – Disciplinary Offerings)

Firsties provide input to development of PEOs during the program briefing in January.

# Chemical Engineering Student Outcomes

## Program Student Outcome 8

The chemical engineering curriculum closely tracks the topics in the Fundamentals of Engineering Exam

On completion of the chemical engineering program, our graduates demonstrate an ability to understand …

- Chemistry
- Material and energy balances
- Safety and environmental factors.
- **Thermodynamics of physical and chemical equilibria**
- Heat, mass, and momentum transfer
- Chemical reaction engineering
- Continuous and staged separation processes
- Process dynamics and control
- Modern experimental and computing techniques
- Process design.

Published in the USMA Redbook (Part 2 – Disciplinary Offerings)

Red designates course emphasis; Black designates heavy usage in course; Gray designates minor emphasis

# Student Outcomes, cont.

The Chemical Engineering Major contains the student outcomes recommended by ABET.

On completion of the chemical engineering program, our graduates demonstrate an ability to …

Published in the USMA Redbook
(Part 2 – Disciplinary Offerings)

- Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- Communicate effectively with a range of audiences.
- Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
- Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
- Design and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
- Acquire and apply new knowledge as needed, using appropriate learning strategies.

Red designates course emphasis; Black designates heavy usage in course; Gray designates minor emphasis

# Redbook

3.0 Credit Hours (BS=0.0, ET=3.0, MA=0.0)

Prerequisites: MA366, MC312, CH364, CH363

Lessons: 40 @ 55 min

Labs: 0 @ 0 min

Course web site:

https://usarmywestpoint.sharepoint.com/sites/cls.ch365/MainPage/default.aspx

# Assessment AY2022-1

| count | event | points ea. | points | percent |
|:-----:|-------|:----------:|:------:|:-------:|
| 1 | TEE | 500 | 500 | 20.58 |
| 1 | Capstone | 300 | 300 | 12.35 |
| 3 | IPRs | 30 | 90 | 3.70 |
| 3 | WPRs | 200 | 600 | 24.69 |
| 68 | Problems | 10 | 680 | 27.98 |
| 1 | Resume | 200 | 200 | 8.34 |
| 1 | SIS Quiz | 60 | 60 | 2.47 |
|  | *Total* |  | *2430* | *100.00* |

Notes:

Problems are 10 points each and collected as *Problem Sets*

Problem Sets are entered in AMS and the point value varies from 30 to 90 points.

# Documentation Policy

Documentation of Academic Work (DAW), July 2017

- **Assignments**
    - Cover sheets are required for all graded events.
    - Must be completed in accordance with instructions in App B
    - Assignments will not be accepted without a cover sheet.
    - Example cover sheet for individual paper submission, App B1
    - Problem sets are documented, App E
    - Document all assistance and collaboration, App A
    - Document internet and e-sources as per *Little Brown*, App D
    - E-submissions – **single** e-signed pdf
- **Formal groups are by assignment.**
    - Definition: see Section 6.l, p. 15
- **Intent of DAW is honesty and integrity**
    - Do not imply that someone else's idea or work is your own.
    - Self-referencing is required.
    - Give credit where it is due.

Instructions for adding additional initial or CAC-signatures to your cover sheet are linked on the wen site at "eSignatures in Adobe."

A fillable cover sheet pdf form is linked to the web site

# Textbook – Paper Copy – ~~Required~~ Preferred
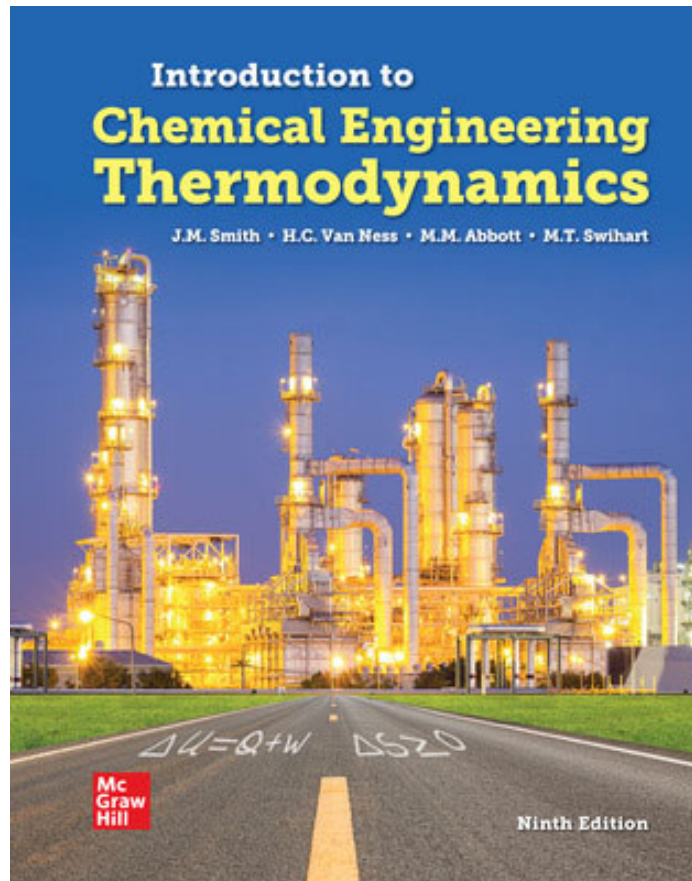


First edition in 1949; very influential book.

ISBN: 978-1-260-72147-8

Instructor is using 1st printing

**Introduction to Chemical Engineering Thermodynamics**
**Copyright © 2022 by The McGraw-Hill Companies, Inc.**
Smith, Van Ness, Abbott, Swihart

# Parts of the Course

Where we are going - roadmap

- Chapter Coverage

  - Chapter 1 – Fundamentals

  - Chapter 2 – First Law

  - Chapter 3 – Properties of Pure Fluids

  - Chapter 4 – Heat Effects

  - Chapter 5 – Entropy

  - Chapter 6 – Real Fluids

  - Chapter 10 – Solution Thermodynamics

  - Chapters 12 and 13 – Phase Equilibria

- Chemical Engineering Perspective

# What you will learn in this course

Where you are going – end state

- How are physical properties calculated?

- How does the CHEMCAD thermodynamics wizard work?

- What is an activity coefficient?  Fugacity?

- What is an equation of state? How many are there? Which one is best?

- How does an equation of state allow calculation of properties like enthalpy and entropy?

- How are the properties of a solution calculated?

Critical chemical engineering questions addressed in this course.

# Admin Questions?

# Scope of Thermodynamics

- Originally – how much work (or power) from heat

    - "Primitive laws" (no contrary experience)

    - Derivation of a network of equations that are general.

- Chemical systems - how much product can I make?

    - Heat and work requirements for physical and chemical processes

- Determination of properties when data are unavailable

# Dimensions and Units

## 1 second

duration of 9,192,631 cycles of radiation emitted from the hyperfine transition in the ground state of cesium-133

## 1 meter

distance light travels in vacuum in 1/299,792,458 of a sec

## 1 kilogram

mass of platinum-iridium cylinder at the International Bureau of Weights and Measures at Sevres, France

## 1 kelvin

1/273.16 of the triple point of water

English units – use conversion factors – App A, pp 648-649

1 ft = 0.3048 m        1 $lb_m$ = 0.45359237 kg        1 lb-mol = 453.59237 mol

# Measures of Amount or Size

- mass, m

- moles, n

note the "t"

- total volume, $V^t$

$$n = \frac{m}{M} \text{ or } m = nM$$

M = molar mass

molar volume

note plain V

$$V = \frac{V^t}{n} \text{ or } V^t = nV$$

specific volume

$$V = \frac{V^t}{m} \text{ or } V^t = mV$$

$$\rho = \frac{1}{V}$$

# Force

1 Newton = the force which when applied to a mass of 1 kg creates an acceleration of 1 m s$^{-2}$

$$\text{force} [=] \frac{(kg)(m)}{s^2} \quad \text{and} \quad 1\,N [=] 1\frac{(kg)(m)}{s^2}$$

1 lb$_f$ is the amount of force, when applied to a mass of 1 lb$_m$ , produces an acceleration of 32.1740 ft s$^{-2}$

but:     $\text{force} [=] lb_f$          $F = \dfrac{1}{g_c} ma$          need conversion factor $g_c$

# Gravitational Conversion, $g_c$

Both EE and SI systems use it

$$F = \frac{1}{g_c}ma \qquad\qquad\qquad F = ma$$

English Engineering Units: | SI Units:
--- | ---

If force is in $lb_f$: $\qquad\qquad$ If force is in $N$:

$$1\left(lb_f\right) = \frac{1}{g_c} \times 1\left(lb_m\right) \times 32.1740\left(ft\right)\left(s^{-2}\right) \qquad 1\left(N\right) = \frac{1}{g_c} \times 1\left(kg\right) \times 1\left(m\right)\left(s^{-2}\right)$$

$$g_c = 32.1740\frac{\left(ft\right)\left(lb_m\right)/s^2}{lb_f} \qquad\qquad g_c = 1\frac{\left(kg\right)\left(m\right)/s^2}{N}$$

# Example Problem

What is the value of $g_c$ and what are its units in a [unit] system in which the second, the foot, and the pound-mass are defined as in Section 1.2, and the unit of force is the poundal, defined as the force required to give 1 lb$_m$ an acceleration of 1 ft/s$^2$?

The poundal is the unit of force in the foot-pound-second (FPS) system of units. The symbol for the poundal is pdl.

In SI units, this problem can be re-worded as follows: What is the value of $g_c$ and what are its units in a [unit] system in which the second, the meter, and the kilogram are defined as in Section 1.2, and the unit of force is the Newton, defined as the force required to give 1 kg an acceleration of 1 m/s$^2$?

# Temperature Units

Fig. 1.1



| Celsius | Kelvin | Fahrenheit | Rankine | |
|---|---|---|---|---|
| 100(°C) | 373.15 K | 212(°F) | 671.67(R) | Steam point |
| 0.01°C | 273.16 K | 32.018 °F | 491.688 K | |
| 0(°C) | 273.15 K | 32(°F) | 491.67(R) | Ice point |
| −273.15(°C) | 0 K | −459.67(°F) | 0(R) | Absolute zero |
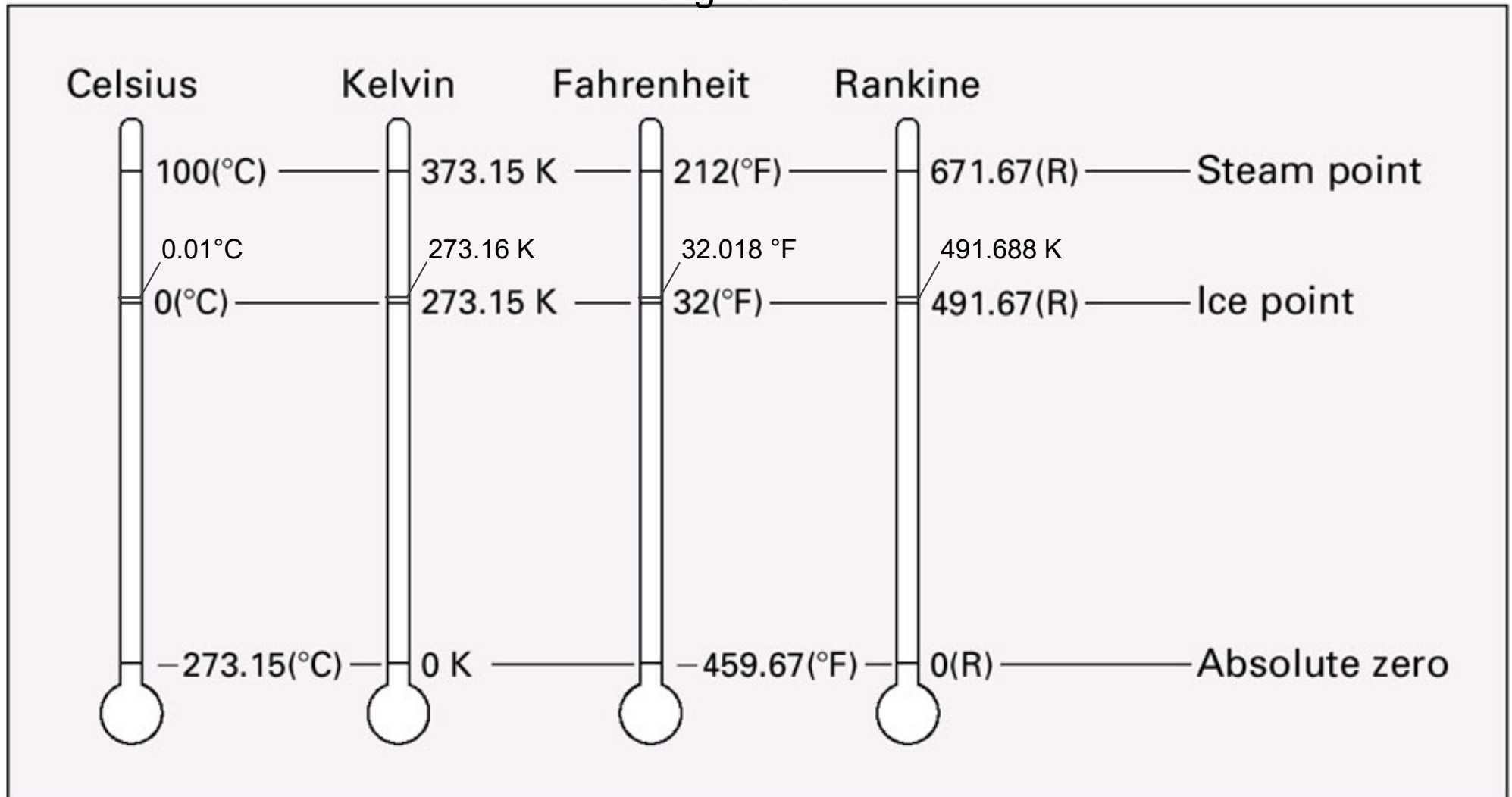
$$°C = K - 273.15 \qquad °F = 1.8°C + 32$$

$$°F = R - 459.67 \qquad R = 1.8K$$

# Temperature Measurement

**Liquid-in-glass**
Bimetallic strips
Thermocouples
Resistance thermometers
Thermistors
Pyrometers
Infrared

LIQUID LEVEL

BATH

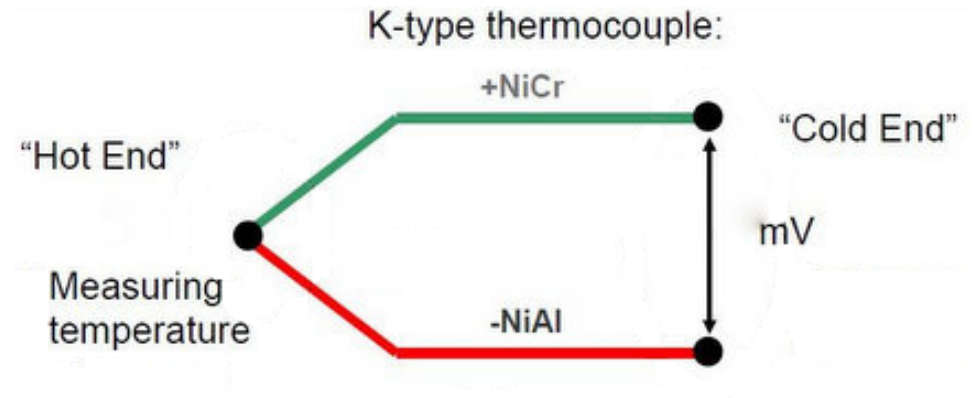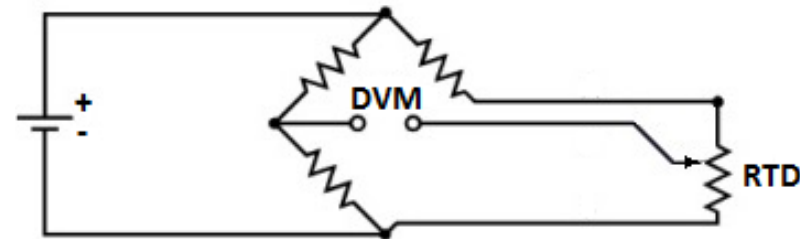# Temperature Measurement

Liquid-in-glass
**Bimetallic strips**
Thermocouples
Resistance thermometers
Thermistors
Pyrometers
Infrared

Steel

Brass

Heating

# Temperature Measurement

Liquid-in-glass
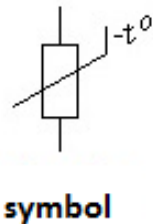Bimetallic strips
**Thermocouples**
Resistance thermometers
Thermistors
Pyrometers
Infrared

K-type thermocouple:

+NiCr

"Hot End"                                    "Cold End"

mV

Measuring
temperature              -NiAl
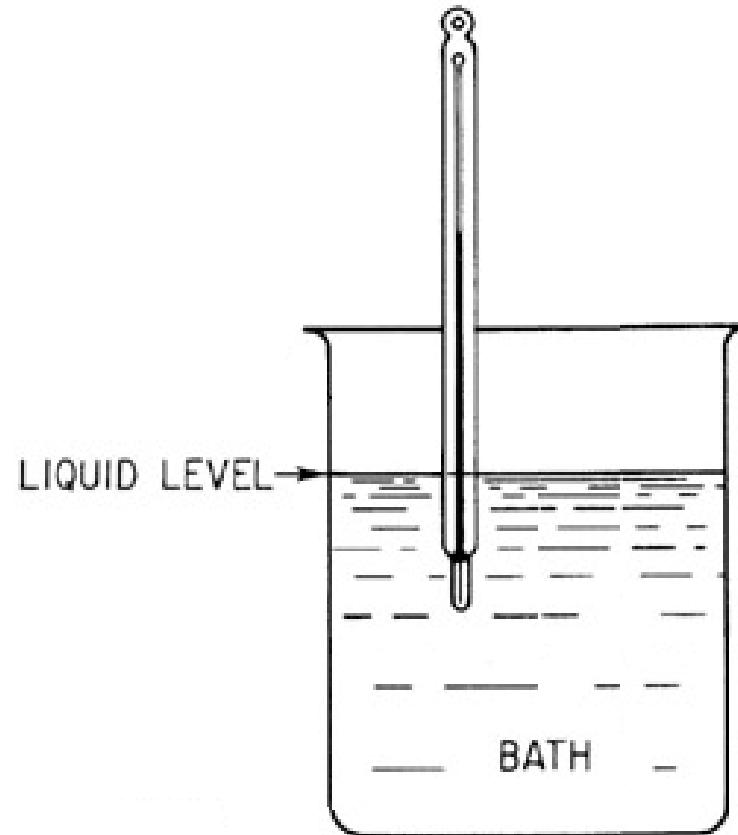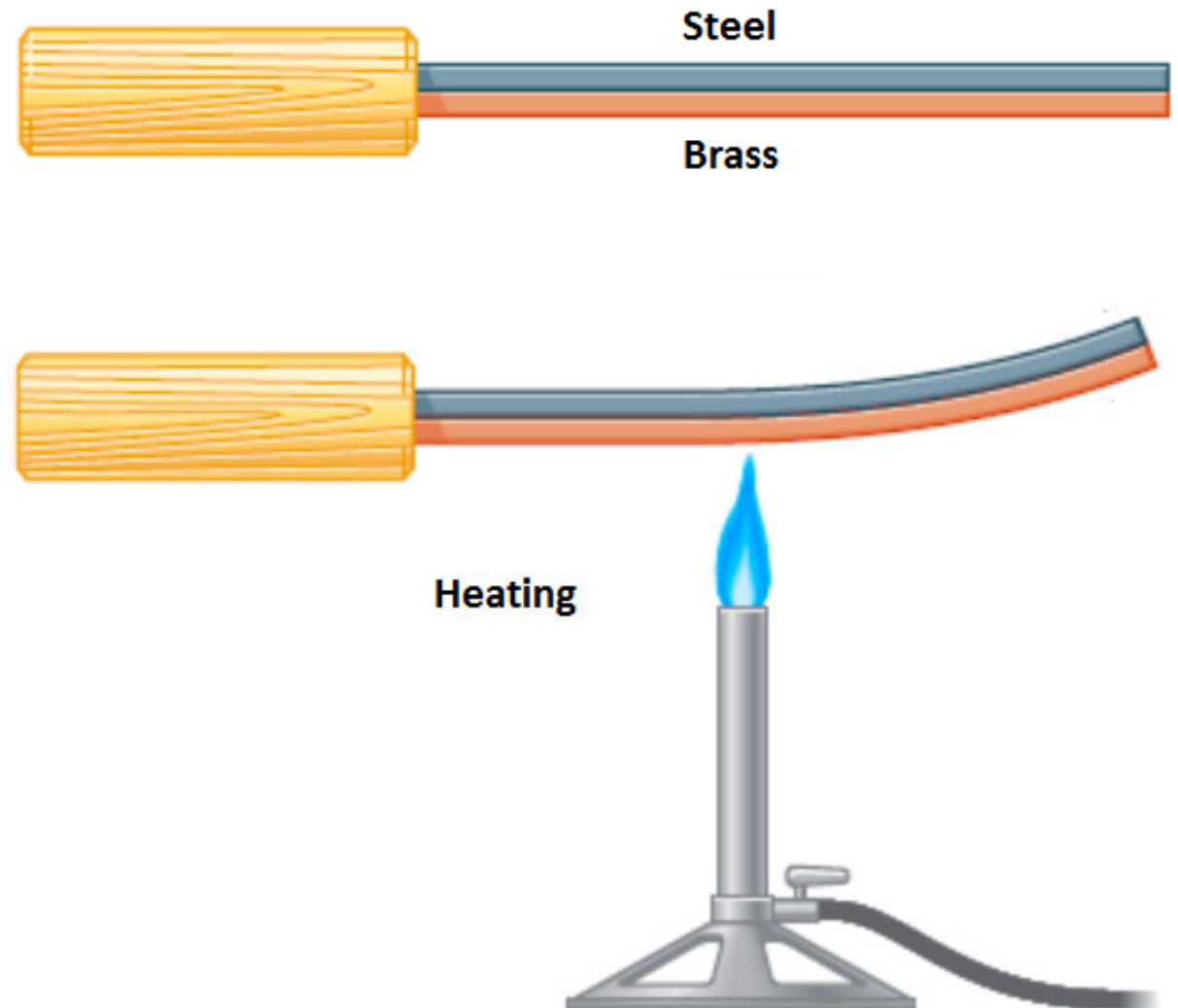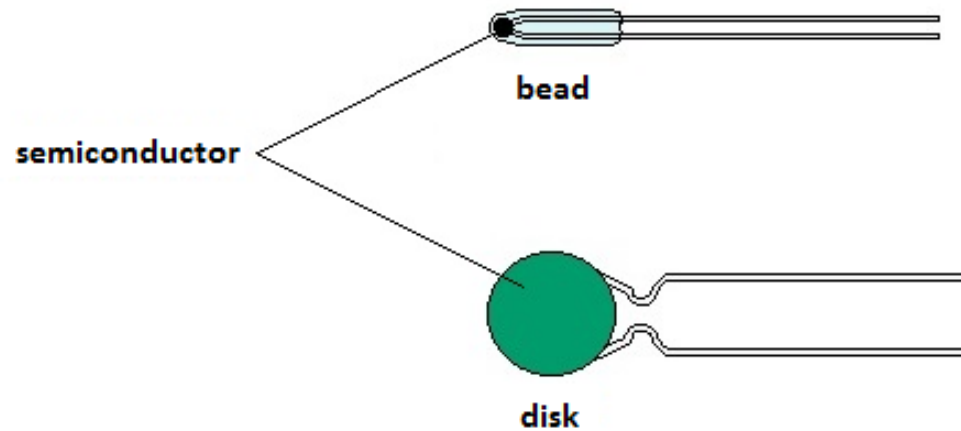
# Temperature Measurement

Liquid-in-glass
Bimetallic strips
Thermocouples
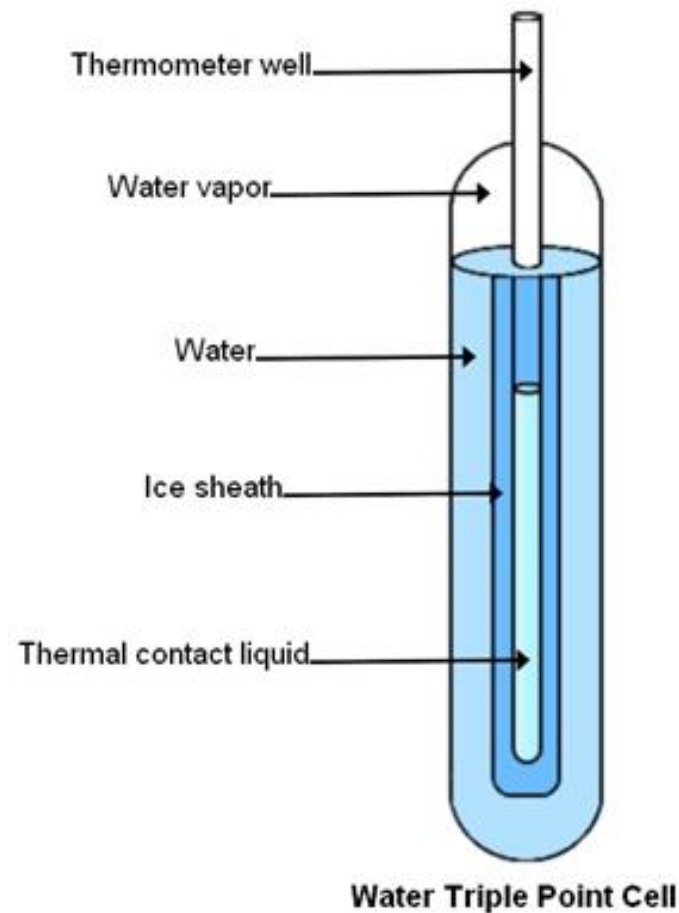**Thermistors**
**Resistance thermometers**
Thermal Radiation

All calibrated against primary standard:

semiconductor

bead

disk

$-t°$

symbol

DVM

+
-

RTD

resistance - function of T

# Temperature Measurement

All calibrated against primary standard:

Thermometer well

Water vapor

Water

Ice sheath

Thermal contact liquid

**Water Triple Point Cell**

# Pressure

## Fig. 1.2



$$P = \frac{F}{A} = \frac{mg}{A}$$

http://www.instrumentationtoolbox.com/
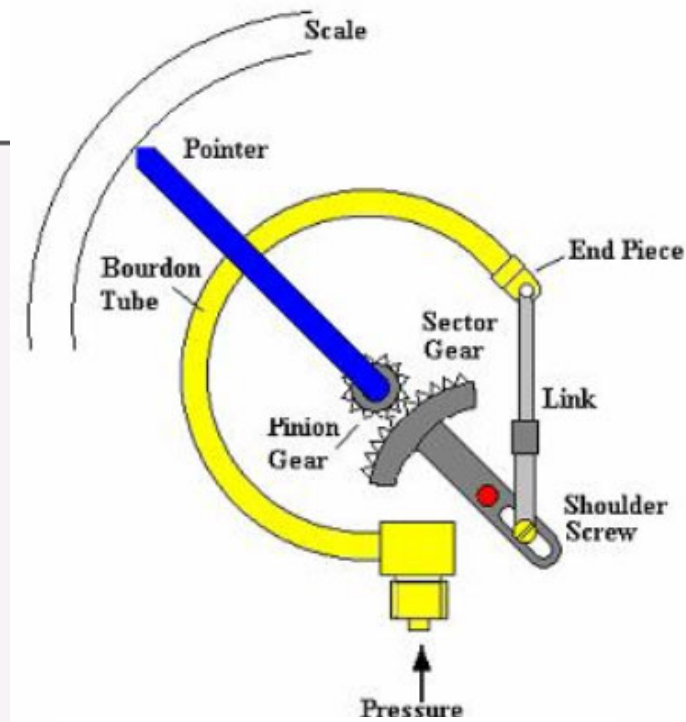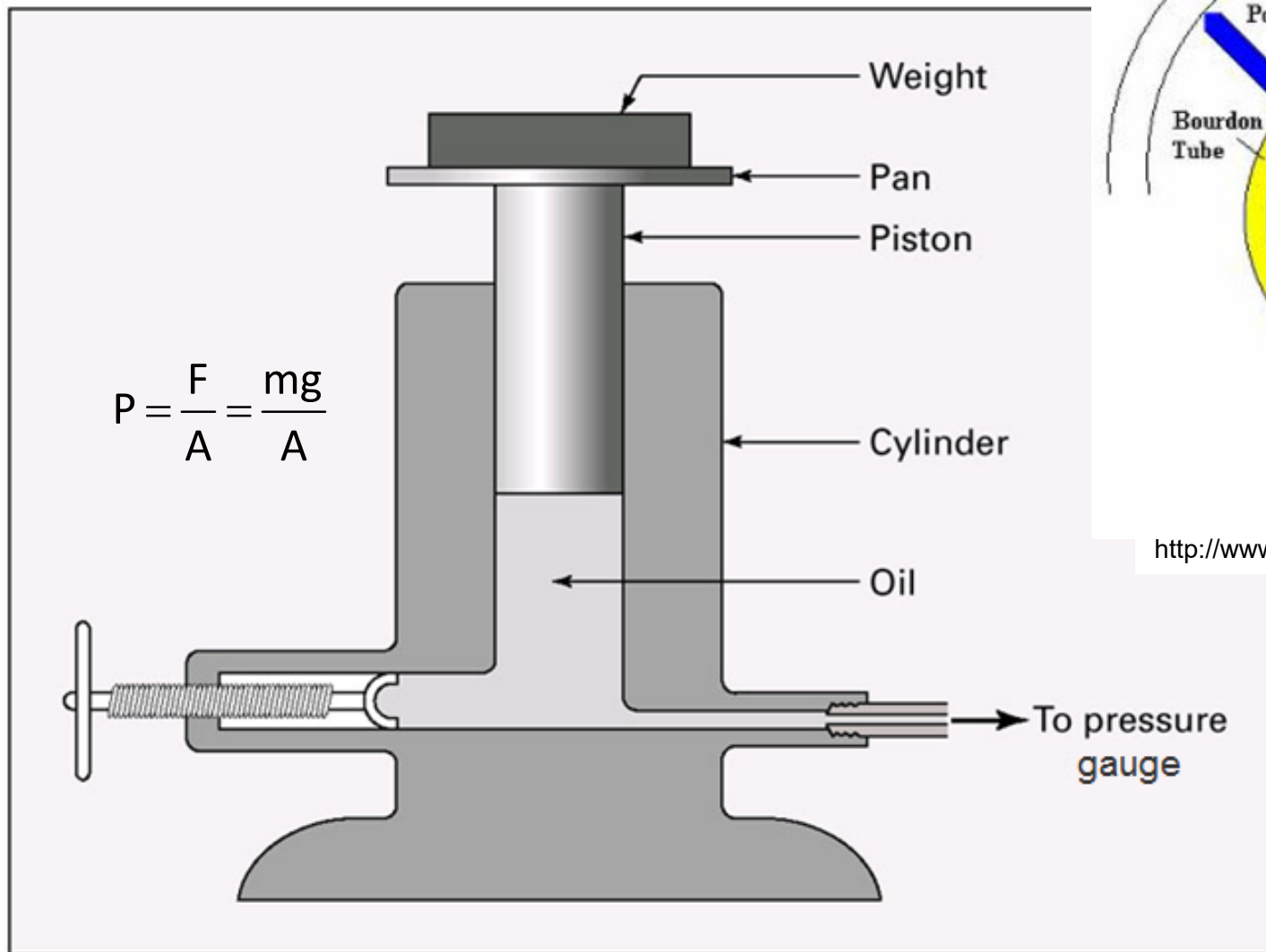
Also: $P = \dfrac{F}{A} = \dfrac{mg}{A} = \dfrac{Ah\rho g}{A} = h\rho g$ (manometers)

# Manometers



Unknown Pressure
Fluid of interest
(Gas in most cases)

$P$

$P_0$

Ambient Fluid
(Atmospheric pressure
in most cases)

$h$

Reference Fluid
Density $\rho$
(Liquid, e.g.,
water or mercury)
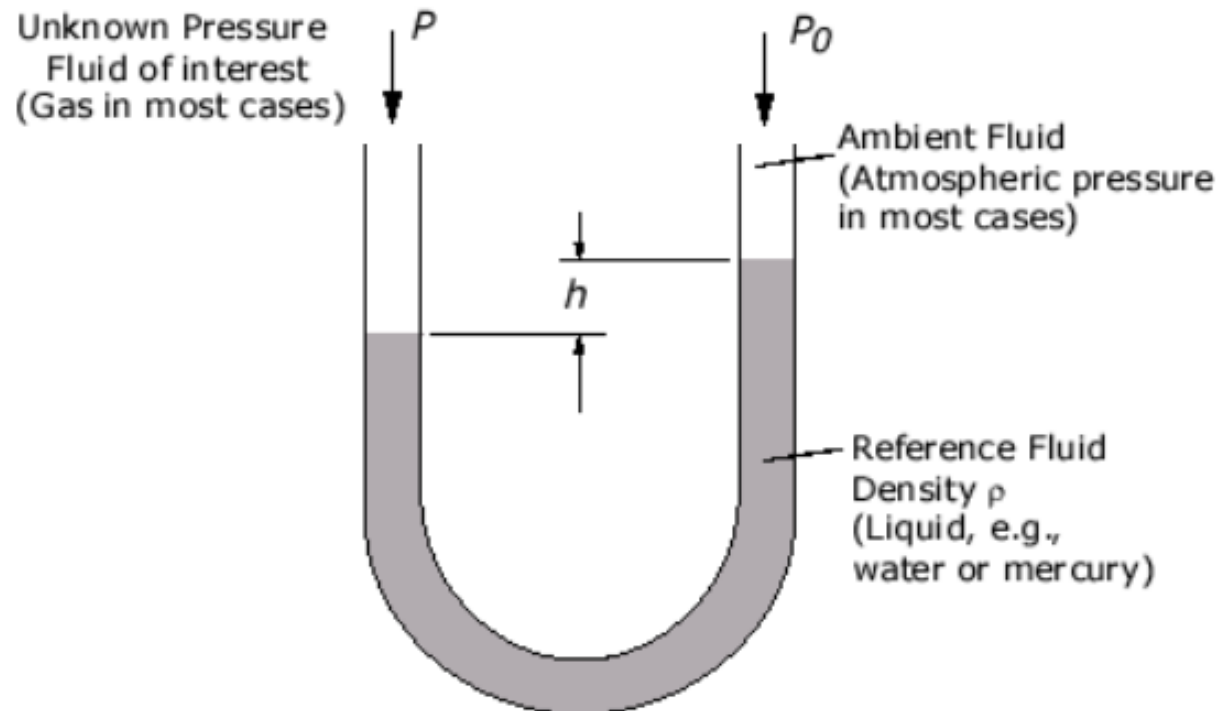
Gauge Pressure $\Delta P = P - P_0 = \rho g h$

# Questions?

# Lesson 1 Problems

# Problem 1.4

At what absolute temperature do the Celsius and Fahrenheit temperature scales give the same numerical value?

# Problem 1.6

Pressures up to 3,000 bar are measured with a dead-weight gauge.  The piston diameter is 4 mm.  What is the approximate mass in kg of the weights required?

# Problem 1.9

The reading on a mercury manometer at 70 °F (open to the atmosphere at one end) is 25.62 inches.  Atmospheric pressure is 29.86 inches of mercury (of mercury).  What is the absolute pressure in psia being measured?  The density of mercury at 70 °F is 13.543 gm/cm$^3$ and the local acceleration of gravity is 32.243 ft/s$^2$.