PHY 113 A General Physics I
9-9:50 AM MWF Olin 101

Plan for Lecture 29:

Chapter 20:

Thermodynamic heat and work

1. **Heat and internal energy**
2. **Specific heat; latent heat**
3. **Work**

21	10/26/2012	Gravitational force	13.1-13.3	13.6, 13.10, 13.13	10/29/2012
22	10/29/2012	Kepler's laws and satellite motion	13.4-13.6	13.28, 13.34	10/31/2012
	10/31/2012	Review	10-13,15		
	11/02/2012	Exam	10-13,15		
23	11/05/2012	Fluid mechanics	14.1-14.4	14.8, 14.24	11/07/2012
24	11/07/2012	Fluid mechanics	14.5-14.7	14.39, 14.51	11/09/2012
25	11/09/2012	Temperature	19.1-19.5	19.1, 19.20	11/12/2012
26	11/12/2012	Heat	20.1-20.4	20.3, 20.14, 20.24	11/14/2012
27	11/14/2012	First law of thermodynamics	20.5-20.7	20.26, 20.35	11/16/2012
28	11/16/2012	Ideal gases	21.1-21.5	21.10, 21.19	11/19/2012
29	11/19/2012	Engines	22.1-22.8	22.6, 22.62	11/26/2012
	11/21/2012	*Thanksgiving Holiday*			
	11/23/2012	*Thanksgiving Holiday*			
	11/26/2012	Review	14,19-22		
	11/28/2012	Exam	14,19-22		
30	11/30/2012	Wave motion	16.1-16.6		12/03/2012
31	12/03/2012	Sound & standing waves	17.1-18.8		12/05/2012
	12/05/2012	Review	1-22		
	12/13/2012	Final Exam – 9 AM			

iclicker question:
Concerning review session for Exam 3

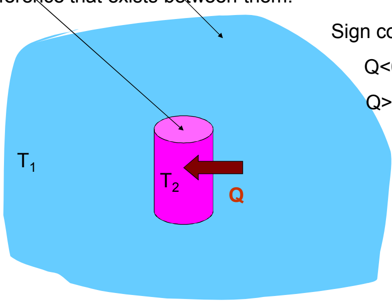
A. **I would like to have a group review session early this week**
B. **I would like to meet individually with NAWH or with a small group to go over the exam**
C. **I am good**

iclicker question:
Scheduling of group review session for Exam 3

A. **Monday (today) at 2 PM**
B. **Monday (today) at 4 PM**
C. **Tuesday at 2 PM**
D. **Tuesday at 4 PM**
E. **Wednesday a 2 PM**

In this chapter T ≡ temperature in Kelvin or Celsius units

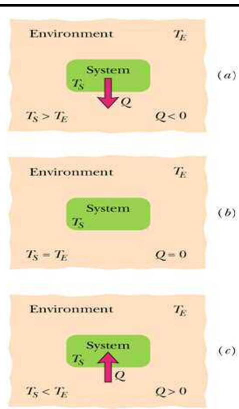
Heat – Q -- the energy that is transferred between a "system" and its "environment" because of a temperature difference that exists between them.



Sign convention:

Q<0 if $T_1 < T_2$

Q>0 if $T_1 > T_2$



Heat **withdrawn** from system

Thermal equilibrium – no heat transfer

Heat **added** to system

Units of heat: Joule

Other units: calorie = 4.186 J

Kilocalorie = 4186 J = Calorie

Note: in popular usage, 1 Calorie is a measure of the heat produced in food when oxidized in the body

iclicker question:
According to the first law of thermodynamics, heat and work are related through the "internal energy" of a system and generally cannot be interconverted. However, we can ask the question: How many times does a person need to lift a 500 N barbell a height of 2 m to correspond to 2000 Calories (1 Calorie = 4186 J) of work?

A. 4186
B. 8372
C. 41860
D. 83720
E. None of these

Heat capacity: C = amount of heat which must be added to the "system" to raise its temperature by 1K (or 1° C).

$Q = C\,\Delta T$

Heat capacity per mass: C=mc

Heat capacity per mole (for ideal gas): $C=nC_v$

$C=nC_p$

More generally:

$$Q_{i\to f} = \int_{T_i}^{T_f} C(T)\,dT$$

Some typical specific heats

Material	J/(kg·°C)	cal/(g·°C)
Water (15°C)	4186	1.00
Ice (-10°C)	2220	0.53
Steam (100°C)	2010	0.48
Wood	1700	0.41
Aluminum	900	0.22
Iron	448	0.11
Gold	129	0.03

iclicker question:

Suppose you have 0.3 kg of hot coffee (at 100 °C). How much heat do you need to remove so that the temperature is reduced to 40 °C? (Note: for water, c=1000 kilocalories/(kg °C))

A. 300 kilocalories (1.256 x 10^6J)
B. 12000 kilocalories (5.023 x 10^7J)
C. 18000 kilocalories (7.535 x 10^7J)
D. 30000 kilocalories (1.256 x 10^8J)
E. None of these

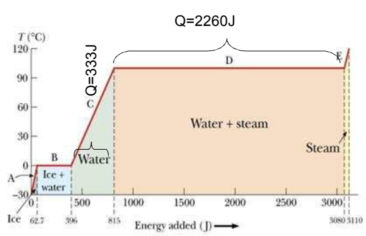
Q=m c ΔT = (0.3)(1000)(100-40) = 18000 kilocalories

Heat and changes in phase of materials

Example: A plot of temperature versus Q added to

1g = 0.001 kg of ice (initially at T=-30°C)

Serway, Physics for Scientists and Engineers, 5/e
Figure 20.2



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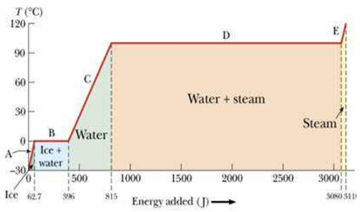


m=0.001 kg

	T_i	T_f	C/L	Q
A	-30 °C	0 °C	2.09 J/°C	62.7 J
B	0 °C	0 °C	333 J	333 J
C	0 °C	100 °C	4.186 J/°C	418.6 J
D	100 °C	100 °C	2260 J	2260 J
E	100 °C	120 °C	2.01 J/°C	40.2 J

Some typical latent heats

Material	J/kg
Ice ⇒Water (0°C)	333000
Water ⇒ Steam (100°C)	2260000
Solid N ⇒ Liquid N (63 K)	25500
Liquid N ⇒ Gaseous N_2 (77 K)	201000
Solid Al ⇒ Liquid Al (660°C)	397000
Liquid Al ⇒ Gaseous Al (2450°C)	11400000

iclicker question:

Suppose you have 0.3 kg of hot coffee (at 100 °C) which you would like to convert to ice coffee (at 0 °C). What is the minimum amount of ice (at 0 °C) you must add? (Note: for water, c=4186 J/(kg °C) and for ice, the latent heat of melting is 333000 J/kg.)

A. 0.2 kg
B. 0.4 kg
C. 0.6 kg
D. 1 kg
E. more

$$m_{water}c(T_f - T_i) + m_{ice}L = 0 \quad m_{ice} = (.3)(4186)(100)/333000$$

Review

Suppose you have a well-insulated cup of hot coffee (m=0.3kg, T=100°C) to which you add 0.3 kg of ice (at 0°C). When your cup comes to equilibrium, what will be the temperature of the coffee?

$$Q = m_{water}c_{water}(T_f - 100) + m_{ice}L_{ice} + m_{ice}c_{water}(T_f - 0) = 0$$

$$(m_{water} + m_{ice})c_{water}T_f = m_{water}c_{water}\cdot 100 - m_{ice}L_{ice}$$

$$T_f = \frac{m_{water}c_{water}\cdot 100 - m_{ice}L_{ice}}{(m_{water} + m_{ice})c_{water}} \qquad m_{water} = m_{ice} = 0.3kg$$

$$c_{water} = 4186\ \mathrm{J/(kg\cdot {}^oC)} \qquad L_{ice} = 333000\ \mathrm{J/kg}$$

$$T_f = 10.22\ {}^o\mathrm{C}$$

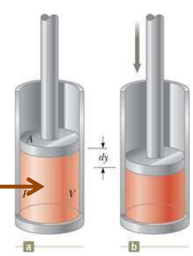
Work defined for thermodynamic process

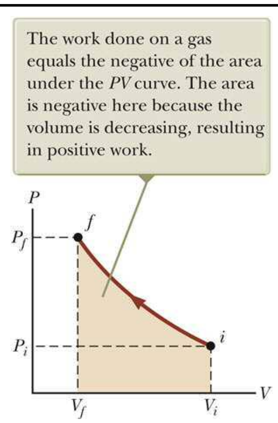
General definition of work :

$$W_{i\to f} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F}\cdot d\mathbf{r}$$

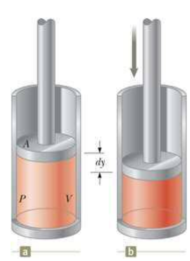
In most text books, thermodynamic work is work done on the "system"

the "system"





$$W = \int_{y_i}^{y_f} F dy = \int_{y_i}^{y_f} \frac{F}{A} A dy = -\int_{V_i}^{V_f} P dV$$



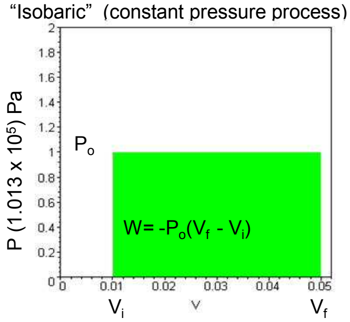
Thermodynamic work

$$W = -\int_{V_i}^{V_f} P\,dV$$

Sign convention: **W > 0 for compression**
W < 0 for expansion

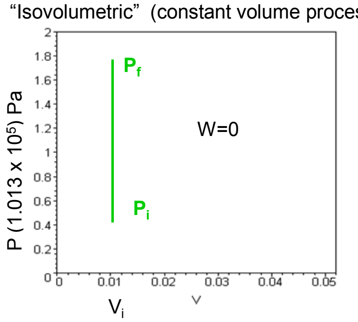
Work done on system --

"Isobaric" (constant pressure process)



Work done on system --

"Isovolumetric" (constant volume process)

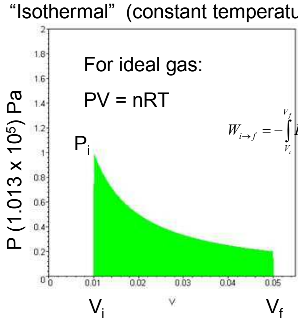


Work done on system which is an ideal gas

"Isothermal" (constant temperature process)

For ideal gas:

PV = nRT



$$W_{i\to f} = -\int_{V_i}^{V_f} P\,dV = -\int_{V_i}^{V_f} \frac{nRT}{V}\,dV = -nRT\ln\left(\frac{V_f}{V_i}\right)$$

$$= -P_iV_i\ln\left(\frac{V_f}{V_i}\right)$$

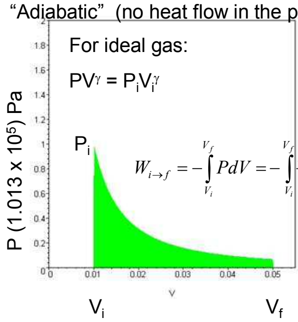
Work done on a system which is an ideal gas:

"Adiabatic" (no heat flow in the process process)

For ideal gas:

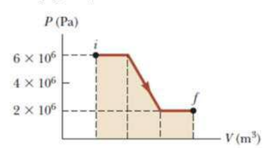
$PV^\gamma = P_iV_i^\gamma$

$Q_{i\to f} = 0$



$$W_{i\to f} = -\int_{V_i}^{V_f} P\,dV = -\int_{V_i}^{V_f} \frac{P_iV_i^\gamma}{V^\gamma}\,dV = -\frac{P_iV_i}{\gamma-1}\left[\left(\frac{V_f}{V_i}\right)^{\gamma-1} - 1\right]$$

Consider the following figure. (The x axis is marked in increments of 0.25 m^3.)



(a) Determine the work done on a gas that expands from i to f as indicated in the figure.

MJ

(b) How much work is performed on the gas if it is compressed from f to i along the same path?

MJ