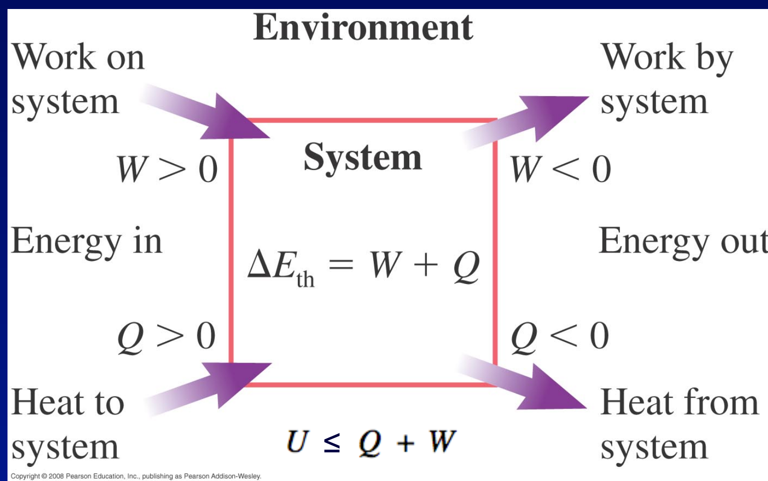
Physics 1021

Spring 2012, 17a

First Law of Thermodynamics

New Topic

The First Law of Thermodynamics



Energy conservation for large systems

Total energy can be no more than the heat input plus the work done to the system

$$\boxed{E_{th} \leq Q + W}$$

- It is clear that there are two things to calculate, Q and W. We will discuss today how to calculate each.
- If we know 2 of the 3 of U, Q, and W, then we can find the third by simple addition. --- this is a very helpful strategy
- U is the same as temperature … we will see this over and over

Iso-what???

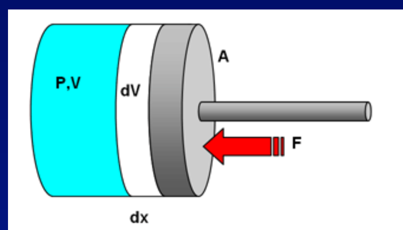
What	Constant
thermal	T -- E does not change
baric	P -- most common experimentally
choric	V – no work done
adiabatic	No heat enters

Work

New Topic

Work done on a gas

The pressure on the wall of a container due to all the molecular collisions is



$dW = Fdx$

$= - PAdx$ (pressure points opposite the force)

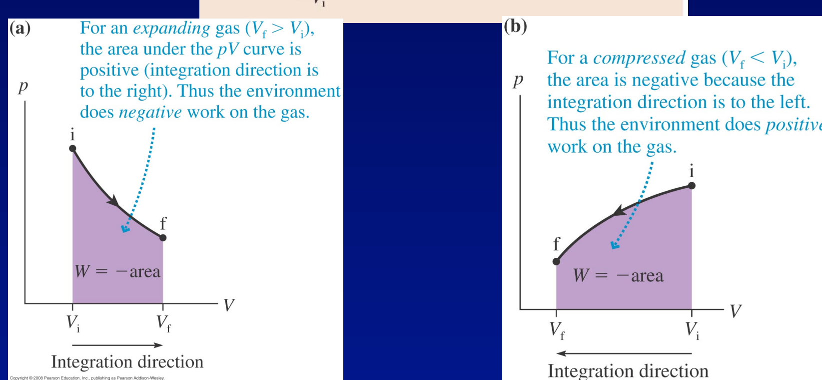
$= - PdV$

The sign makes sense … positive work is done on the gas to **reduce** the volume.

Work done on a gas more details

Pay attention to the signs and then ask yourself afterwards if the overall sign makes sense – use your estimate here.

$$W = -\int_{V_i}^{V_f} p\,dV \qquad \text{(work done on a gas)}$$



$W =$ the negative of the area under the pV curve between V_i and V_f

Energy conservation for large systems

From the discussion on Tuesday, the energy per degree of freedom is:

$$E_{th} = \tfrac{1}{2} k_B T$$

For a monoatomic gas, this is written – Note that there is no difference between E and E_{th}, both are kinetic + potential energy:

$$E_{th} = \frac{3}{2} N k_B T = \frac{3}{2} PV$$

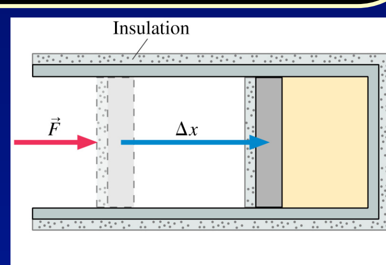
Sometimes (often) the symbol U is used.

$$U = \frac{3}{2} N k_B T = \frac{3}{2} PV$$

ConcepTest 17a.1 Work

A gas cylinder and piston are covered with heavy insulation. The piston is pushed into the cylinder, compressing the gas. In this process, the gas temperature

1. doesn't change.
2. decreases.
3. increases.
4. there's not sufficient information to tell.



ConcepTest 17a.1 Work

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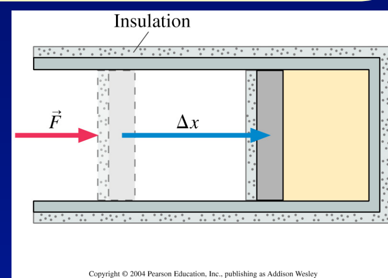
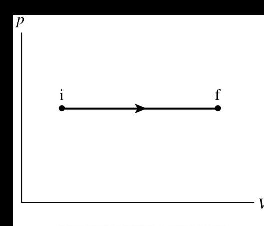
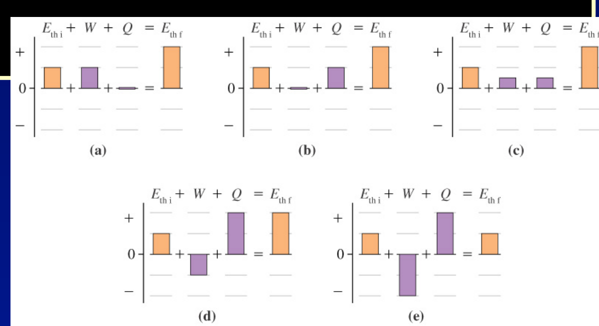
Work is done on the gas to compress it … this increases the internal energy



ConcepTest 17a.2 Work

Which first-law bar chart describes the process shown in the *pV* diagram?





ConcepTest 17a.2 Work

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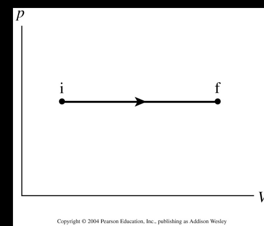
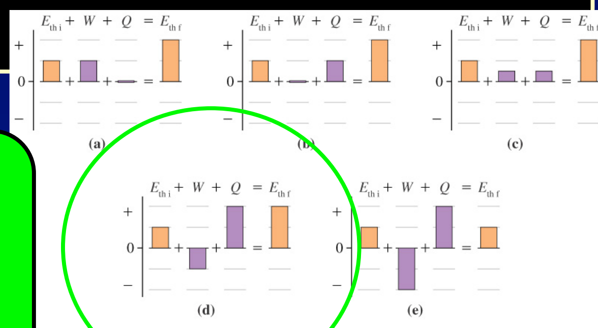
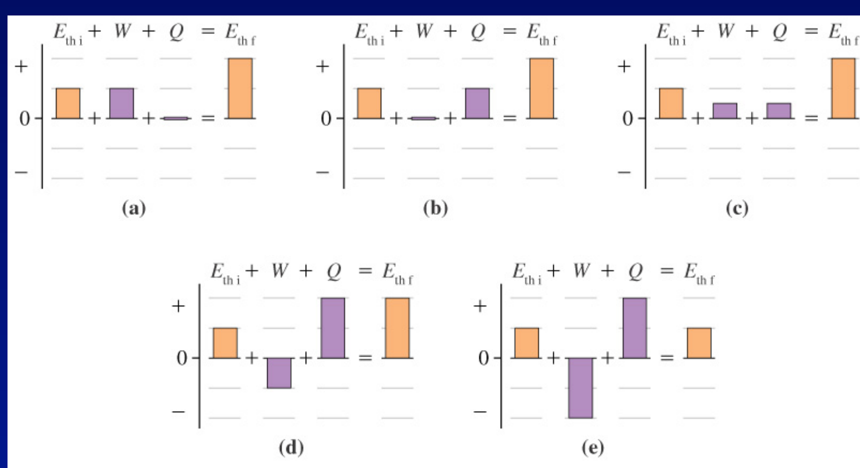




Negative work is done and PV → U increases

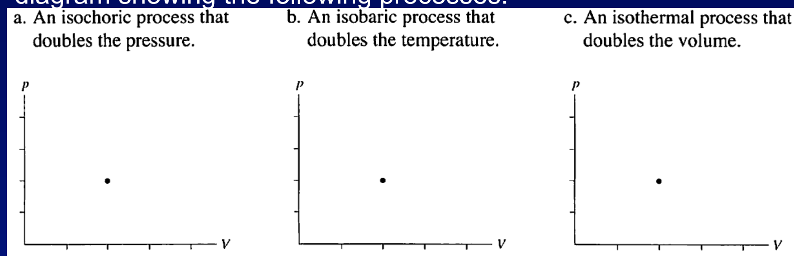
Ponderable: Iso what ???

For processes A-F below, label the type of process. e is isothermal, the others are …?



Ponderable: PV Diagrams, Mapping the States of an Ideal Gas

1. The graphs below show the initial state of a gas. Draw a PV diagram showing the following processes:



2. Interpret the pV diagrams shown below by
   1. Naming the process.
   2. Stating the factors by which p, V, and T change. (A fixed quantity changes by a factor of 1.)

Ponderable: PV Diagrams, Mapping the States of an Ideal Gas 2/3

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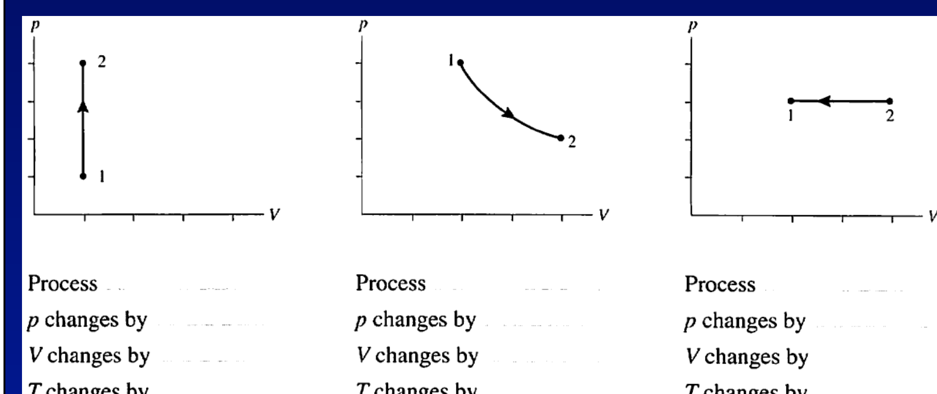
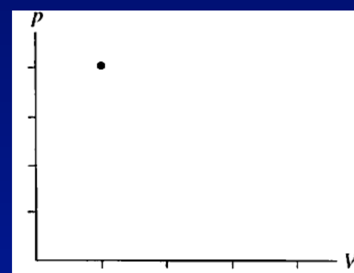


Ponderable: PV Diagrams, Mapping the States of an Ideal Gas 3/3

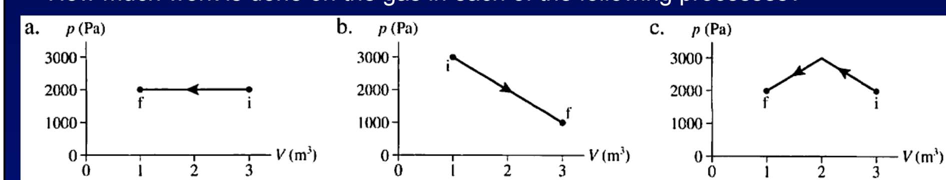
3. Starting from the initial state shown, draw a PV diagram for the three step process:
   1. An isochoric process that halves the temperature, then
   2. An isothermal process that halves the pressure, then
   3. An isobaric process that doubles the volume.

Label each of the stages on your diagram.

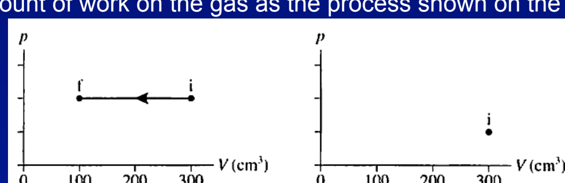


Ponderable: Work done on a gas increases its internal energy

How much work is done on the gas in each of the following processes?

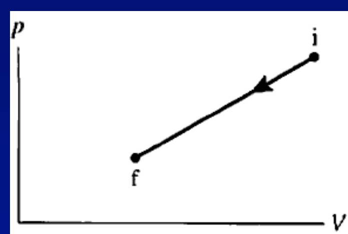


1. Knowing the initial and final pressures and volumes, what is the change in the internal energy for each of the processes.
2. Now, how much heat is input (output) for each of the above processes?
3. The figure on the left shows a process in which a gas is compressed from 300 cm^3 to 100 cm^3. On the right set of axes, draw the PV diagram of a process that starts from initial state i, compresses the gas to 100 cm^3, and does the same amount of work on the gas as the process shown on the left.



Ponderable: Work done on a gas increases its internal energy Continued

1. The figure shows a process in which work is done to compress a gas.
2. Draw and label a process A that starts and ends at the same points but does more work on the gas.
3. Draw and label a process B that starts and ends at the same points but does less work on the gas.



Specific Heat

New Topic

Temperature Change and Specific Heat

The amount of energy that raises the temperature of 1 kg of a substance by 1 K is called the **specific heat** of that substance. The symbol for specific heat is *c*.

If $W = 0$, so no work is done by or on the system, then the heat needed to bring about a temperature change ΔT is

$$Q = Mc\Delta T \qquad \text{(temperature change)}$$

Temperature Change and Specific Heat

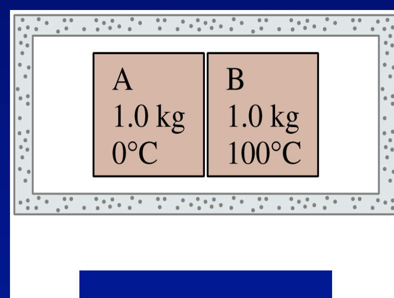
TABLE 17.2 Specific heats and molar specific heats of solids and liquids

Substance	c (J/kg K)	C (J/mol K)
Solids		
Aluminum	900	24.3
Copper	385	24.4
Iron	449	25.1
Gold	129	25.4
Lead	128	26.5
Ice	2090	37.6
Liquids		
Ethyl alcohol	2400	110.4
Mercury	140	28.1
Water	4190	75.4

ConcepTest 17a.3 Heat Capacity

Objects A and B are brought into close thermal contact with each other, but they are well isolated from their surroundings. Initially $T_A = 0°C$ and $T_B = 100°C$. The specific heat of A is more than the specific heat of B. The two objects will soon reach a common final temperature T_f. The final temperature is

1. $T_f > 50°C$.
2. $T_f = 50°C$.
3. $T_f < 50°C$.



18, Pg 23

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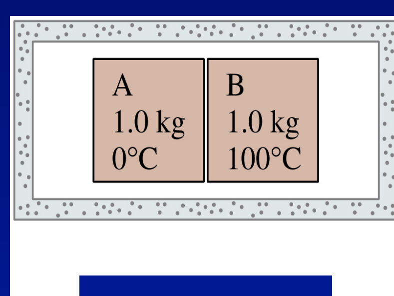
1. $T_f > 50°C$.
2. $T_f = 50°C$.
3. $T_f < 50°C$.

The final temperature (energy) is the same for each, since A has a higher C_v, it must have a larger ΔT.

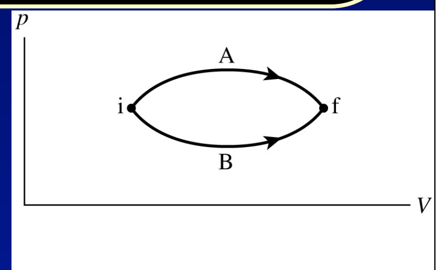


18, Pg 24

ConcepTest 17a.4 Work

For the two processes shown, which of the following is true:

1. $Q_A < Q_B$.
2. $Q_A = Q_B$.
3. $Q_A > Q_B$.

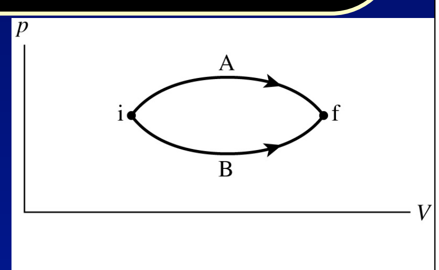


ConcepTest 17a.4 Work

For the two processes shown, which of the following is true:

1. $Q_A < Q_B$.
2. $Q_A = Q_B$.
3. $Q_A > Q_B$.

The initial and final temperatures are the same. On path A, the system does more work, so there must be more heat added to compensate for the extra work done



The Specific Heats of Gases

It is useful to define two different versions of the specific heat of gases, one for constant-volume (isochoric) processes and one for constant-pressure (isobaric) processes. We will define these as molar specific heats because we usually do gas calculations using moles instead of mass. The quantity of heat needed to change the temperature of n moles of gas by ΔT is

$$Q = nC_V\Delta T \qquad \text{(temperature change at constant volume)}$$

$$Q = nC_P\Delta T \qquad \text{(temperature change at constant pressure)}$$

where C_V is the **molar specific heat at constant volume** and C_P is the **molar specific heat at constant pressure**.

The Specific Heats of Gases

TABLE 17.4 Molar specific heats of gases (J/mol K)

Gas	C_P	C_V	$C_P - C_V$
Monatomic Gases			
He	20.8	12.5	8.3
Ne	20.8	12.5	8.3
Ar	20.8	12.5	8.3
Diatomic Gases			
H_2	28.7	20.4	8.3
N_2	29.1	20.8	8.3
O_2	29.2	20.9	8.3

Example: Specific heat

In a laboratory environment, it is much easier to hold pressure constant than volume, so if heat is applied to a sample with a know C_v, held at constant pressure, what will be the rise in temperature?

Ponderable: Isothermal expansion of a gas

On the whiteboard, draw a PV diagram, and sketch (accurately) on it an isotherm. Now Sketch a second isotherm at a different temperature than the first. Think about the following:

1. What is the work done in compressing the gas, following the first isotherm.

2. Draw three lines connecting the two isotherms and rank them in order based on the change in internal energy (U) that they represent.

Ponderable: Isothermal expansion of a gas 2

1. Now think about the isothermal expansion of a monoatomic gas from a volume V to a volume 2V. How much heat must be input to accomplish this change?

2. From Monday's class, you were introduced to the idea of entropy and that $dQ = TdS$. What is the change in entropy for the above expansion?