Review of lecture 1

Temperature

Different temperature scales

Thermal expansion $\Delta L = L\alpha\,\Delta T,$ $\Delta V = V\beta\,\Delta T,$

Can β be negative?

Temperature and Heat

$$Q = C\,\Delta T = C(T_f - T_i), \qquad Q = cm\,\Delta T = cm(T_f - T_i).$$

Phases of matter and phase changes

$$Q = Lm.$$

Thermal contact

Heat absorbed and released

18-5 The First Law of Thermodynamics

* If an enclosed gas expands or contracts, calculate the work W done by the gas by integrating the gas pressure with respect to the volume of the enclosure.
* Identify the algebraic sign of work W associated with expansion and contraction of a gas.
* Given a *p*-*V* graph of pressure versus volume for a process, identify the starting point (the initial state) and the final point (the final state) and calculate the work by using graphical integration.
* On a p-V graph of pressure versus volume for a gas, identify the algebraic sign of the work associated with a right-going process and a left-going process.
* Apply the first law of thermodynamics to relate the change in the internal energy ΔE_{int} of a gas, the energy Q transferred as heat to or from the gas, and the work W done on or by the gas.

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18-5 The First Law of Thermodynamics

* Identify the algebraic sign of a heat transfer *Q* that is associated with a transfer to a gas and a transfer from the gas.

* Identify that the internal energy ΔE_{int} of a gas tends to increase if the heat transfer is to the gas, and it tends to decrease if the gas does work on its environment.

* Identify that in an adiabatic process with a gas, there is no heat transfer *Q* with the environment.

* Identify that in a constant-volume process with a gas, there is no work W done by the gas.

* Identify that in a cyclical process with a gas, there is no net change in the internal energy ΔE_{int}.

* Identify that in a free expansion with a gas, the heat transfer *Q*, work done *W*, and change in internal energy ΔE_{int} are each zero.

The First Law of Thermodynamics

The principle of conservation of energy for a thermodynamic process is expressed in the first law of thermodynamics, which may assume either of the forms:

$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W \quad \text{(first law).}$$

Or, if the thermodynamic system undergoes only a differential change, we can write the first law as:

$$dE_{int} = dQ - dW \quad \text{(first law).}$$

W=work done by the system Q=heat absorbed by the system

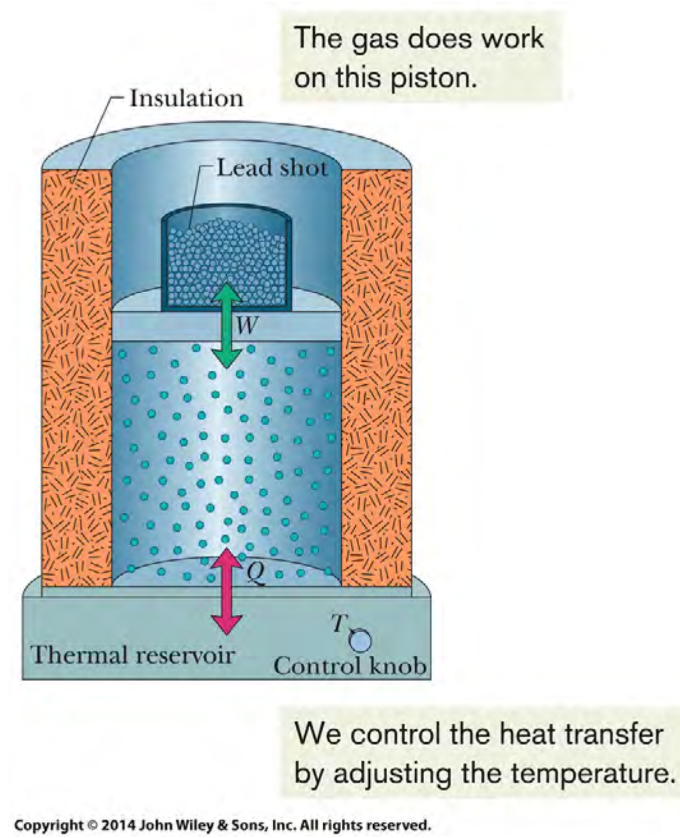
The internal energy E_{int} of a system tends to increase if energy is added as heat Q and tends to decrease if energy is lost as work W done by the system.

Heat and Work

A gas may exchange energy with its surroundings through work. The amount of work W done by a gas as it expands or contracts from an initial volume V_i to a final volume V_f is given by

$$W = \int dW = \int_{V_i}^{V_f} p\, dV.$$

The integration is necessary because the pressure p may vary during the volume change.



A gas confined to a cylinder with a movable piston.

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Pressure: P=force/area=F/A ==> F=PA

Unit of pressure: Pa = Pascal

1Pa = 1N/m^2

another unit of pressure: atm=atmosphere

1atm=1.01x10^5Pa =10.1N/cm^2

Heat and Work

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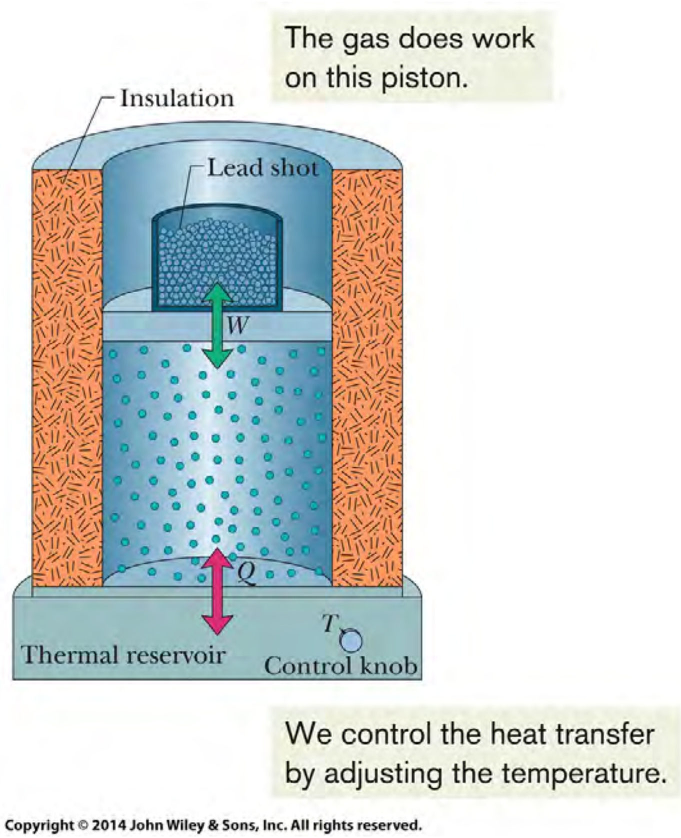

A gas confined to a cylinder with a movable piston.

18-5 The First Law of Thermodynamics

Heat and Work

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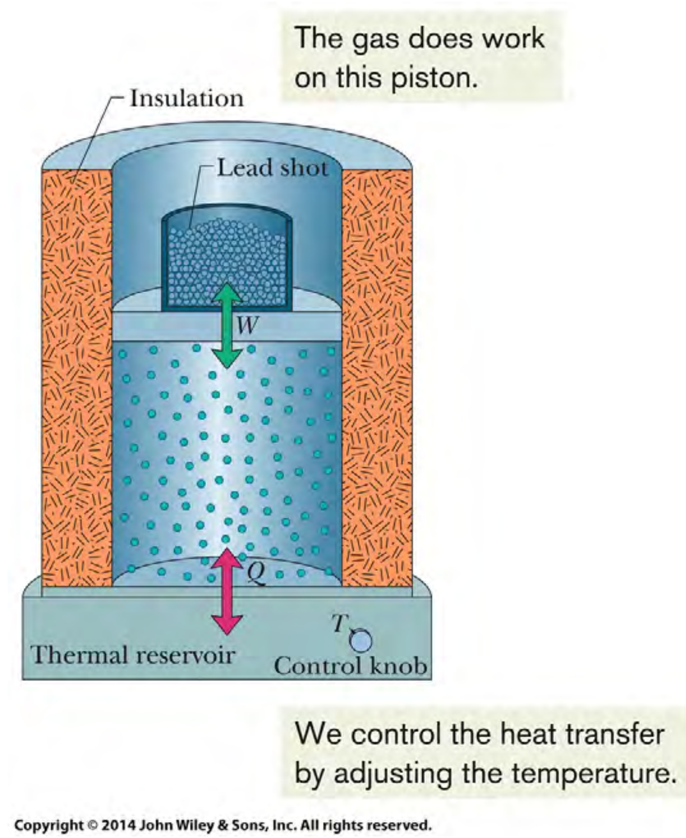
$$W = \int dW = \int_{V_i}^{V_f} p\, dV.$$

Why?

The integration is necessary because the pressure *p* may vary during the volume change.

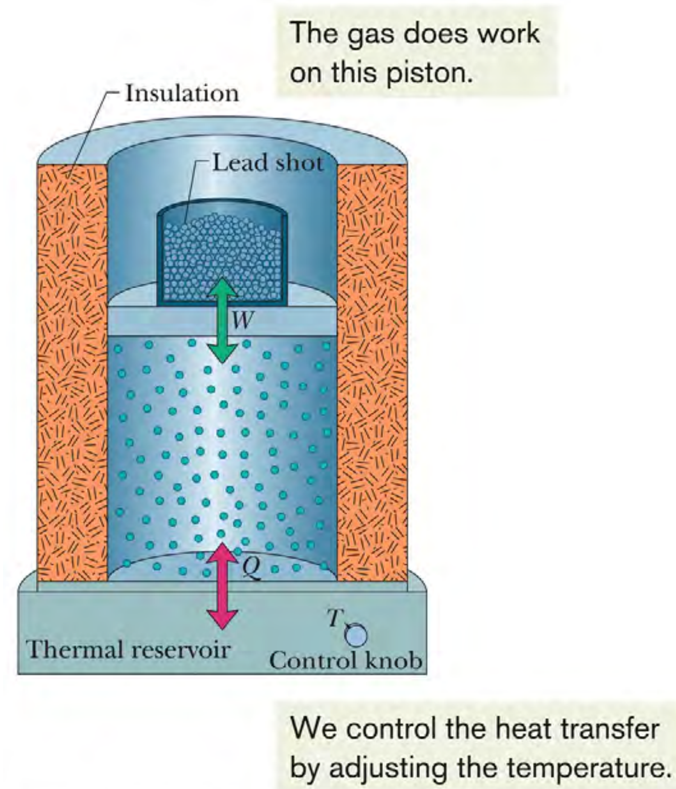


A gas confined to a cylinder with a movable piston.

Pressure: P=force/area=F/A ==> F=PA

Work: W=FΔx   Δx=distance   dW=Fdx

dW=Fdx=PAdx=Pd(Ax)=PdV



$$W = \int dW = \int_{V_i}^{V_f} p\, dV.$$

Pressure: P=force/area=F/A ==> F=PA

Work: $W=F\Delta x$ $\quad \Delta x$=distance $\quad dW=Fdx$

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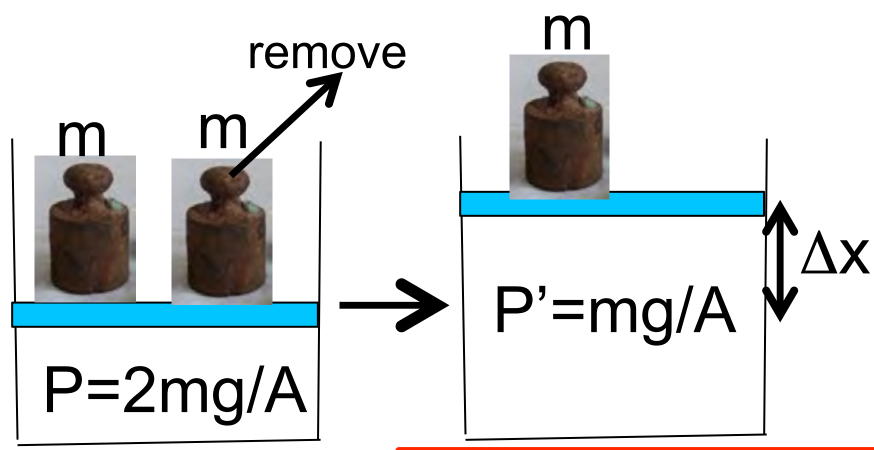
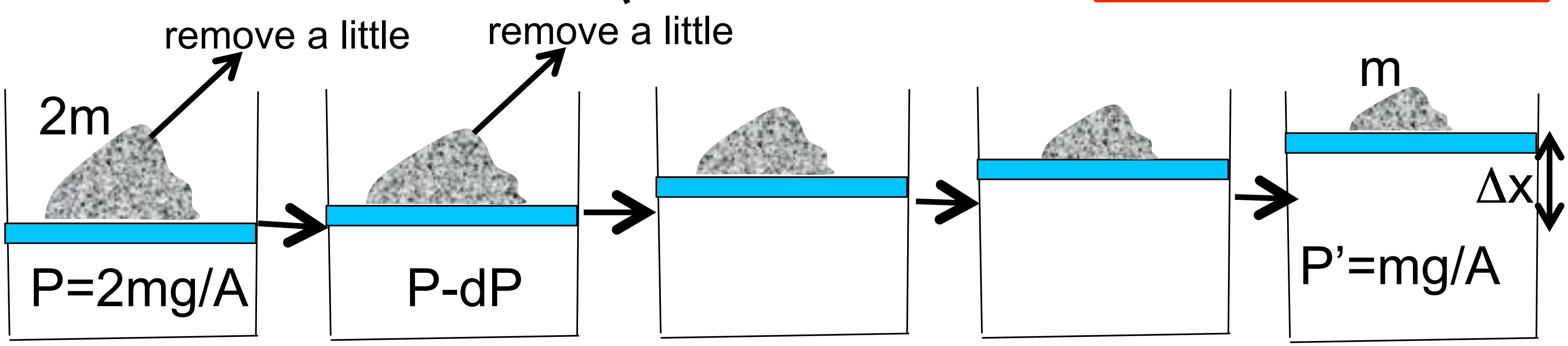


What is W?

W=mgΔx=P' ΔV



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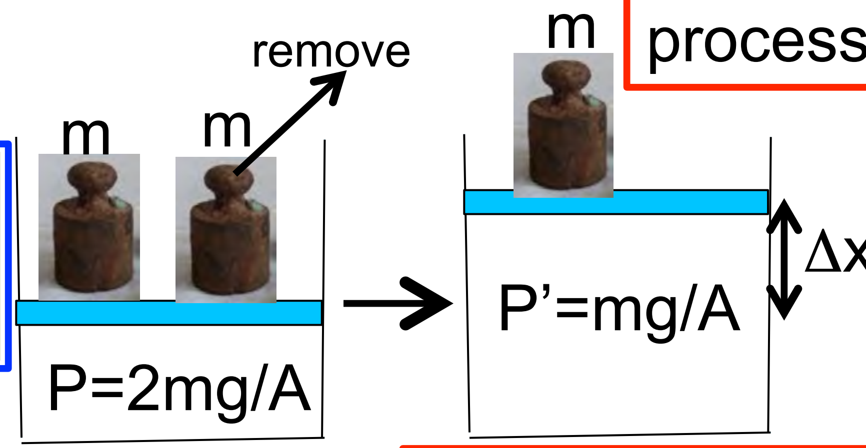
irreversible process



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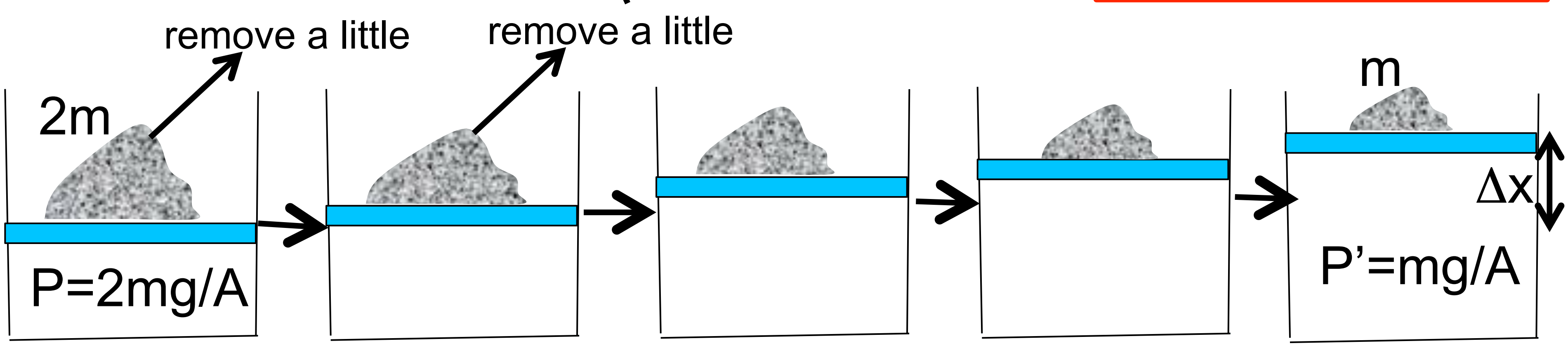
reversible process



What is W?

Pressure: P=force/area=F/A ==> F=PA

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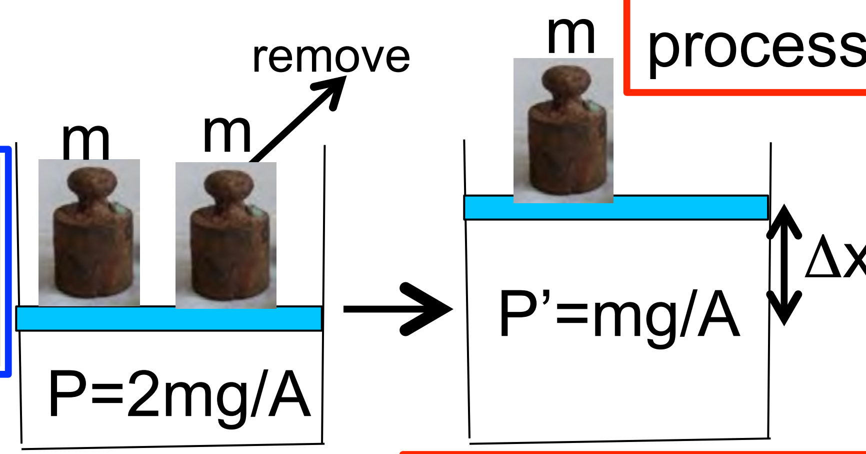
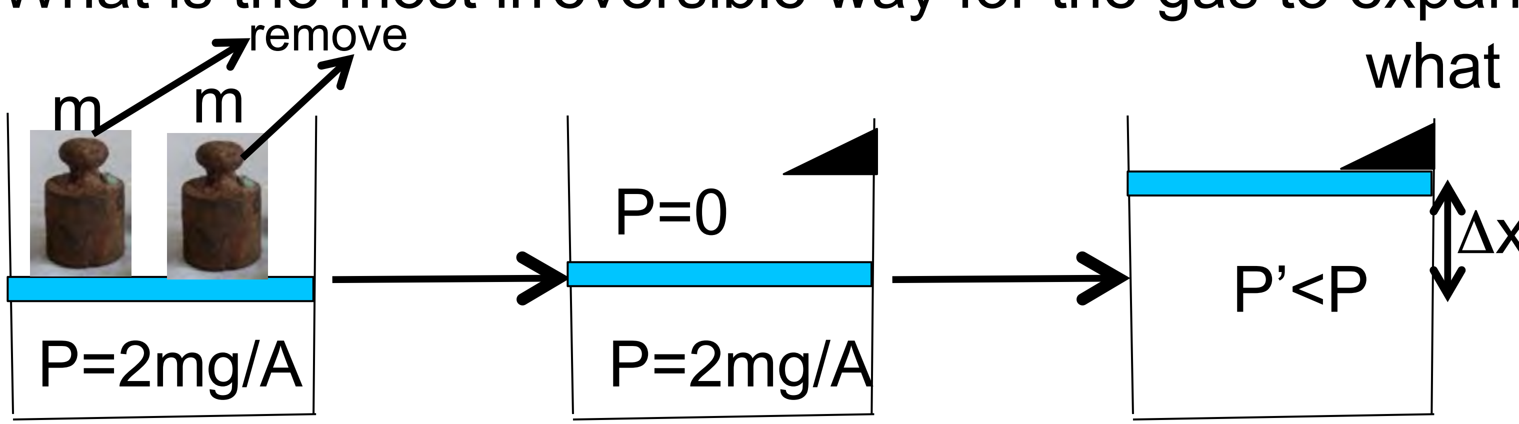


irreversible process

What is W?

$W=mg\Delta x=P'\,\Delta V$

What is the most irreversible way for the gas to expand?

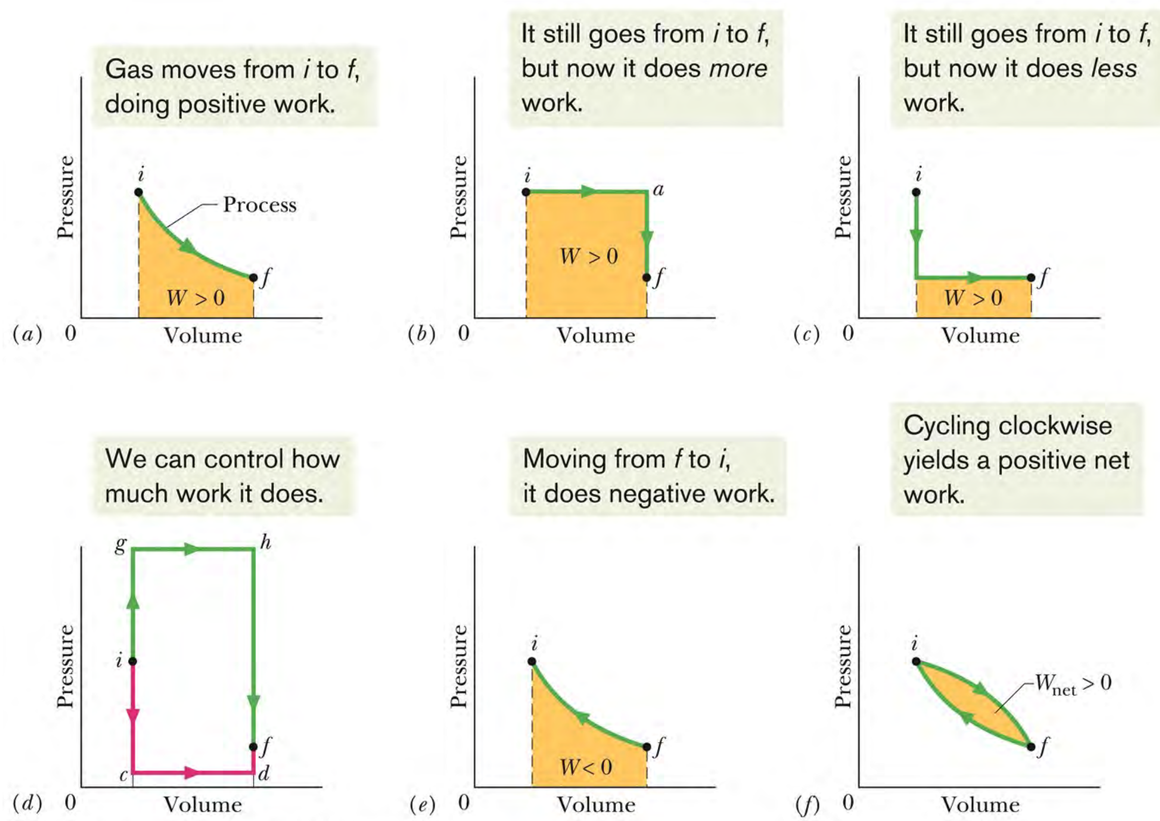


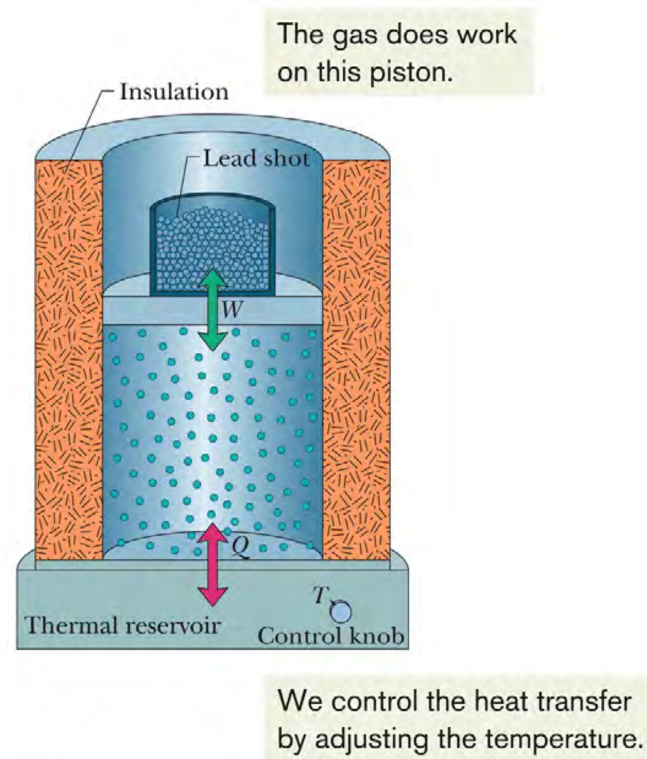
what is W?

W=0
free expansion

18-5 The First Law of Thermodynamics

Heat and Work





A gas confined to a cylinder with a movable piston.

18-5 The First Law of Thermodynamics

Table 18-5 The First Law of Thermodynamics: Four Special Cases

The Law: $\Delta E_{int} = Q - W$ (Eq. 18-26)

Process	Restriction	Consequence
Adiabatic	$Q = 0$	$\Delta E_{int} = -W$
Constant volume	$W = 0$	$\Delta E_{int} = Q$
Closed cycle	$\Delta E_{int} = 0$	$Q = W$
Free expansion	$Q = W = 0$	$\Delta E_{int} = 0$

Exact and inexact differentials

Definition [edit]

An inexact differential is commonly defined as a differential form d*x* where there is no corresponding function *x* such that: $x = \int \mathrm{d}x$. More precisely, an inexact differential is a differential form that cannot be expressed as the differential of a function. In the language of calculus, for a given vector field *F*, $\delta F = F\,\mathrm{d}r$ is an inexact differential if there is no function *f* such that

$$F = \nabla f$$

First law of thermodynamics [edit]

Inexact differentials are known especially for their presence in the first law of thermodynamics:

$$\delta Q = \mathrm{d}U + \delta W$$

The symbol δ instead of the plain d, which originated from the 19th century work of German mathematician Carl Gottfried Neumann,[2] indicates that *Q* (heat) and *W* (work) are path-dependent.

Internal energy *U* is a *state function*, meaning its change can be inferred just by comparing two different states of the system (not its transition path), which we can therefore indicate with U_1 and U_2. Since we can go from state U_1 to state U_2 either by providing heat $Q = U_2 - U_1$ or work $W = U_2 - U_1$, such a change of state does not identify uniquely the values of provided *W* and *Q*, but only the change in internal energy ΔU.

Exact and inexact differentials

Integrating factors [edit]

It is sometimes possible to convert an inexact differential into an exact one by means of an integrating factor. The most common example of this in thermodynamics is the definition of entropy:

$$\mathrm{d}\,S = \frac{\delta Q_{\mathrm{rev}}}{T}$$

In this case, δQ is an inexact differential, because its effect on the state of the system can be compensated by δW. However, when divided by the absolute temperature *and* when the exchange occurs at reversible conditions (therefore the $_{\mathrm{rev}}$ subscript), it produces an exact differential: the entropy S is also a state function.

Inexact differentials are known especially for their presence in the first law of thermodynamics:

$$\delta Q = \mathrm{d}U + \delta W$$

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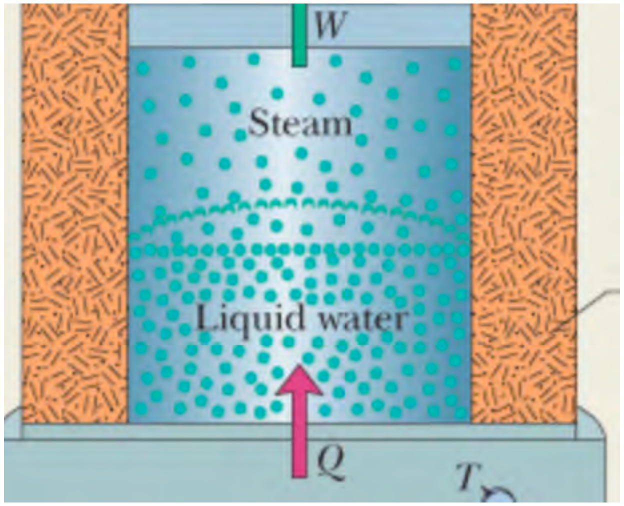
Problem:

1kg of liquid water at 100°C boils at 1 atm pressure.
Volume changes from $10^{-3}m^3$ to $1.671m^3$
Find (a) work done, (b) heat absorbed, (c) change in E_{int}



$P=1.01x10^5Pa$

$W=P(V_f-V_i)=169kJ$

$Q=L_Vm=2256kJ/kgx1kg=2256kJ$

$\Delta E_{int}=Q-W=2256kJ-169kJ=2087kJ$

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18-6 Heat Transfer Mechanisms

* For thermal conduction through a layer, apply the relationship between the energy-transfer rate P_{cond} and the layer's area A, thermal conductivity k, thickness L, and temperature difference ΔT (between its two sides).
* For a composite slab (two or more layers) that has reached the steady state in which temperatures are no longer changing, identify that (by the conservation of energy) the rates of thermal conduction P_{cond} through the layers must be equal.
* For thermal conduction through a layer, apply the relationship between thermal resistance R, thickness L, and thermal conductivity k.
* Identify that thermal energy can be transferred by convection, in which a warmer fluid (gas or liquid) tends to rise in a cooler fluid.

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18-6 Heat Transfer Mechanisms

* In the *emission* of thermal radiation by an object, apply the relationship between the energy-transfer rate P_{rad} and the object's surface area A, emissivity ε, and *surface* temperature T (in kelvins).

* In the *absorption* of thermal radiation by an object, apply the relationship between the energy-transfer rate P_{abs} and the object's surface area A and emissivity ε, and the *environmental* temperature T (in kelvins).

* Calculate the net energy transfer rate P_{net} of an object emitting radiation to its environment and absorbing radiation from that environment.

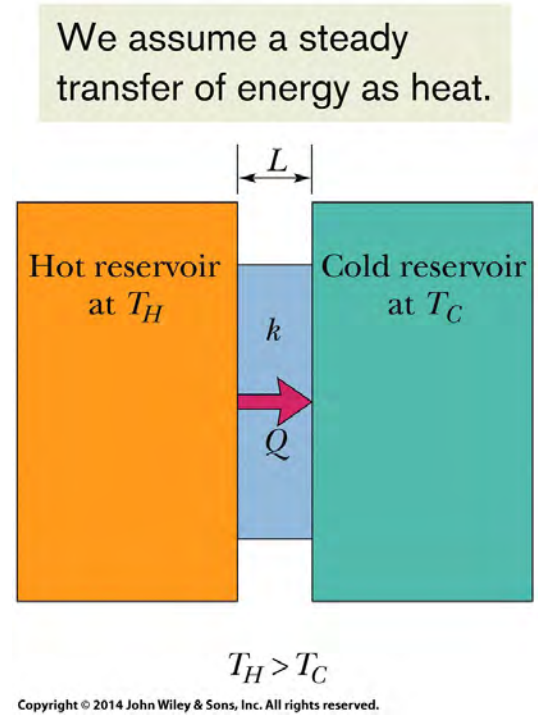
18-6 Heat Transfer Mechanisms

Thermal Conduction

The rate P_{cond} at which energy is conducted through a slab for which one face is maintained at the higher temperature T_H and the other face is maintained at the lower temperature T_C is

$$P_{\text{cond}} = \frac{Q}{t} = kA\,\frac{T_H - T_C}{L},$$

Here each face of the slab has area A, the length of the slab (the distance between the faces) is L, and k is the thermal conductivity of the material.



Energy is transferred as heat from a reservoir at temperature T_H to a cooler reservoir at temperature T_C through a conducting slab of thickness L and thermal conductivity k.

18-6 Heat Transfer Mechanisms

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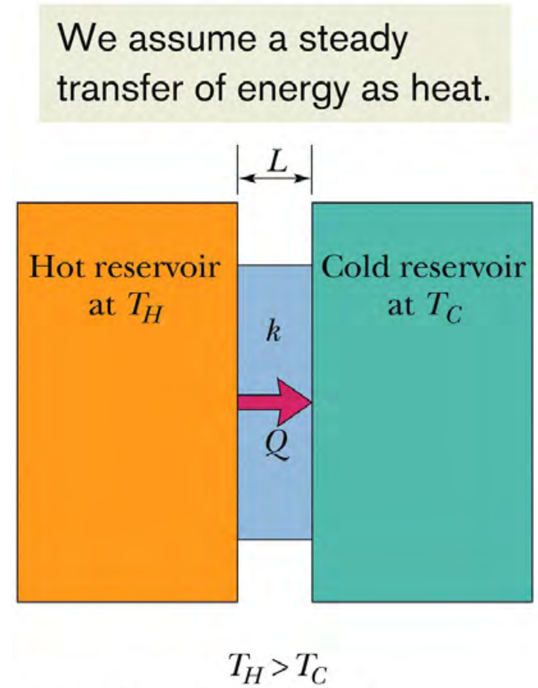
k=W/mK

Cu: 400, glass: 1

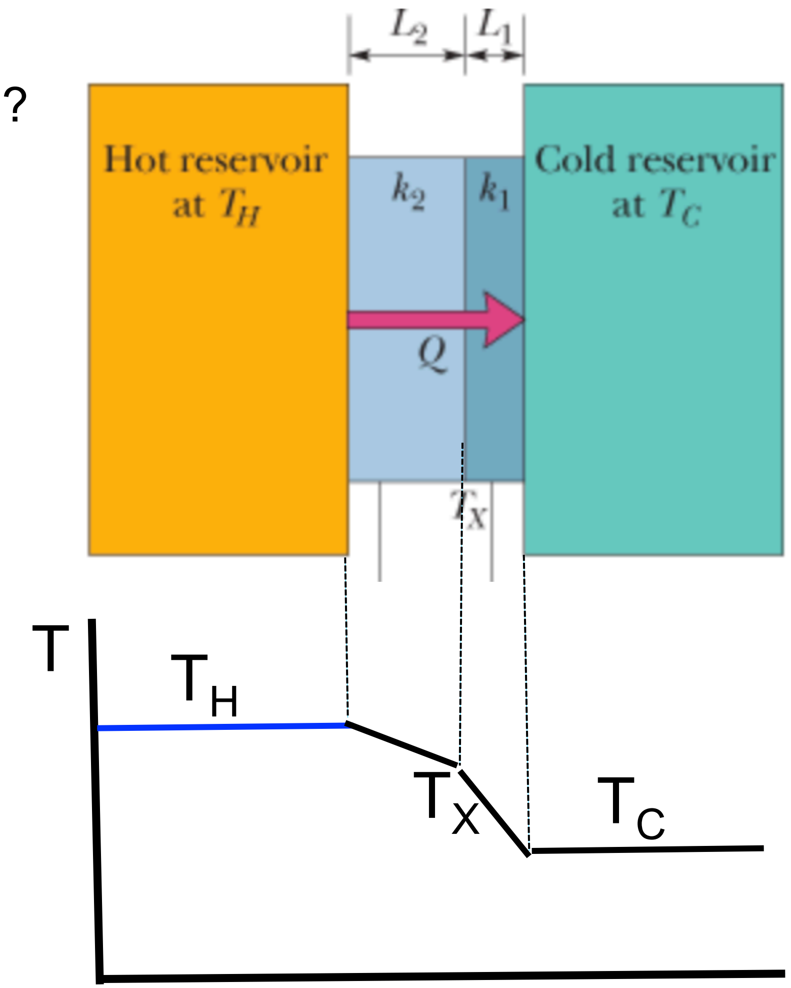


Energy is transferred as heat from a reservoir at temperature T_H to a cooler reservoir at temperature T_C through a conducting slab of thickness *L* and thermal conductivity *k*.

Conduction through a composite slab

$$P_{cond} = \frac{Q}{t} = kA\frac{T_H - T_C}{L},$$

What is P_{cond} here?



$$P_{cond} = \frac{k_2 A(T_H - T_X)}{L_2} = \frac{k_1 A(T_X - T_C)}{L_1}.$$

solve for T_X

$$T_X = \frac{k_1 L_2 T_C + k_2 L_1 T_H}{k_1 L_2 + k_2 L_1}.$$

$$P_{cond} = \frac{A(T_H - T_C)}{L_1/k_1 + L_2/k_2}.$$

$$P_{cond} = \frac{A(T_H - T_C)}{\Sigma(L/k)}.$$

Convection

- Convection occurs when temperature differences cause an energy transfer by motion within a fluid.

- When you look at the flame of a candle or a match, you are watching thermal energy being transported upward by convection.

- Convection is part of many natural processes. Atmospheric convection plays a fundamental role in determining global climate patterns and daily weather vari- ations. Glider pilots and birds alike seek rising thermals (convection currents of warm air) that keep them aloft. Huge energy transfers take place within the oceans by the same process.

18-6 Heat Transfer Mechanisms

Convection

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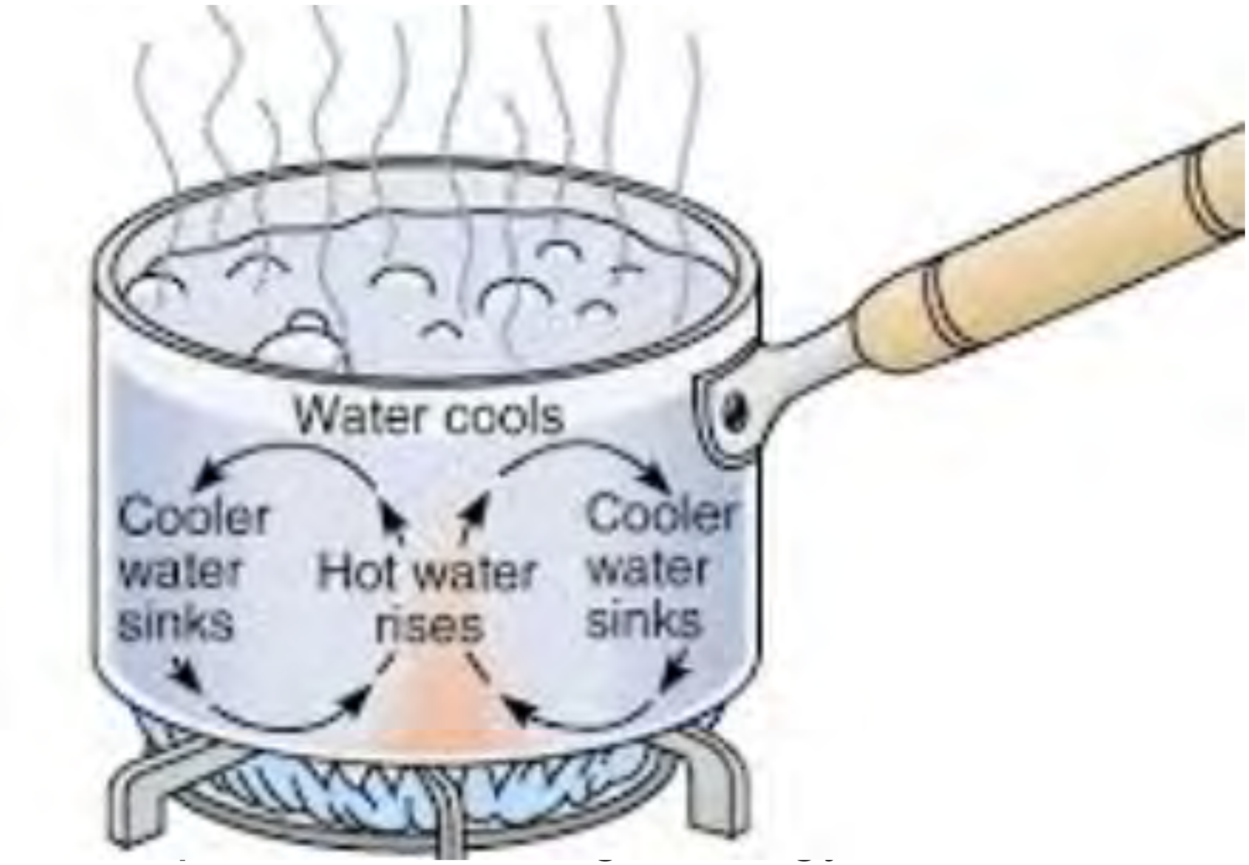
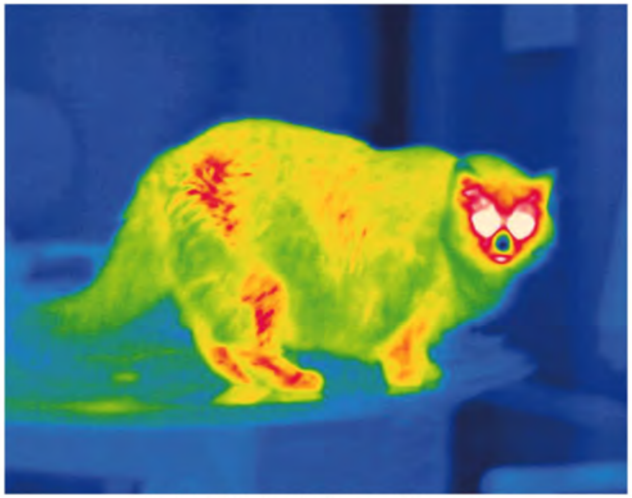


18-6 Heat Transfer Mechanisms

Thermal Radiation

Radiation is an energy transfer via the emission of electromagnetic energy. The rate P_{rad} at which an object emits energy via thermal radiation is

$$P_{rad} = \sigma \varepsilon A T^4.$$



Edward Kinsman/Photo Researchers, Inc.

Here σ (= 5.6704×10^{-8} W/m^2.K^4) is the Stefan– Boltzmann constant, ε is the emissivity of the object's surface, A is its surface area, and T is its surface temperature (in kelvins). The rate P_{abs} at which an object absorbs energy via thermal radiation from its environment, which is at the uniform temperature T_{env} (in kelvins), is

$$P_{abs} = \sigma \varepsilon A T_{env}^4.$$