Chapter 20: The Second Law of Thermodynamics

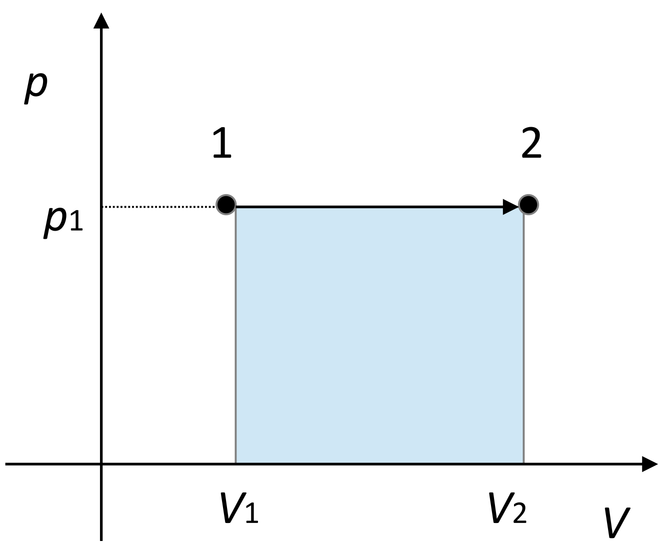
- Do processes have preferential process tendency/direction?
- What are “reversible” and “irreversible” processes?
- How do we compute the disorder change?
- How do we use a heat engine or a refrigerator?

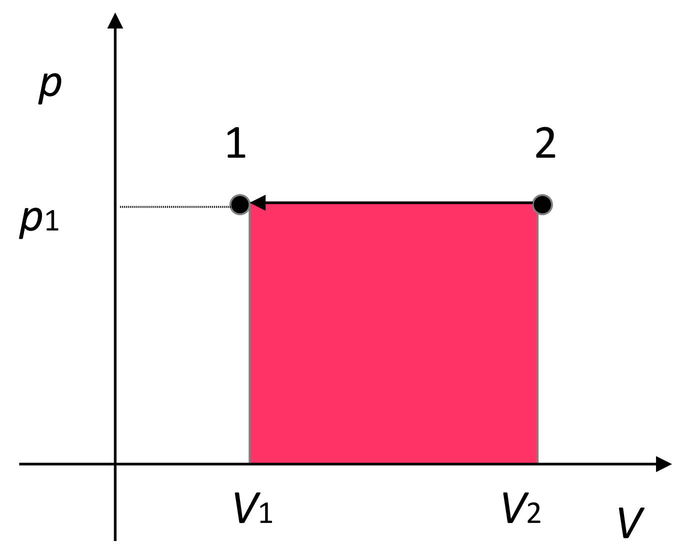
Do processes have preferential process tendency/direction?

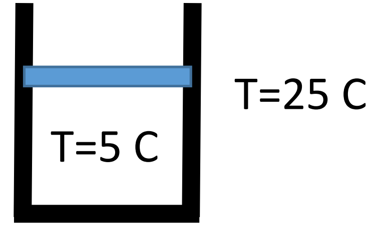
The First Law of Thermodynamics

$$\Delta U = Q - W$$

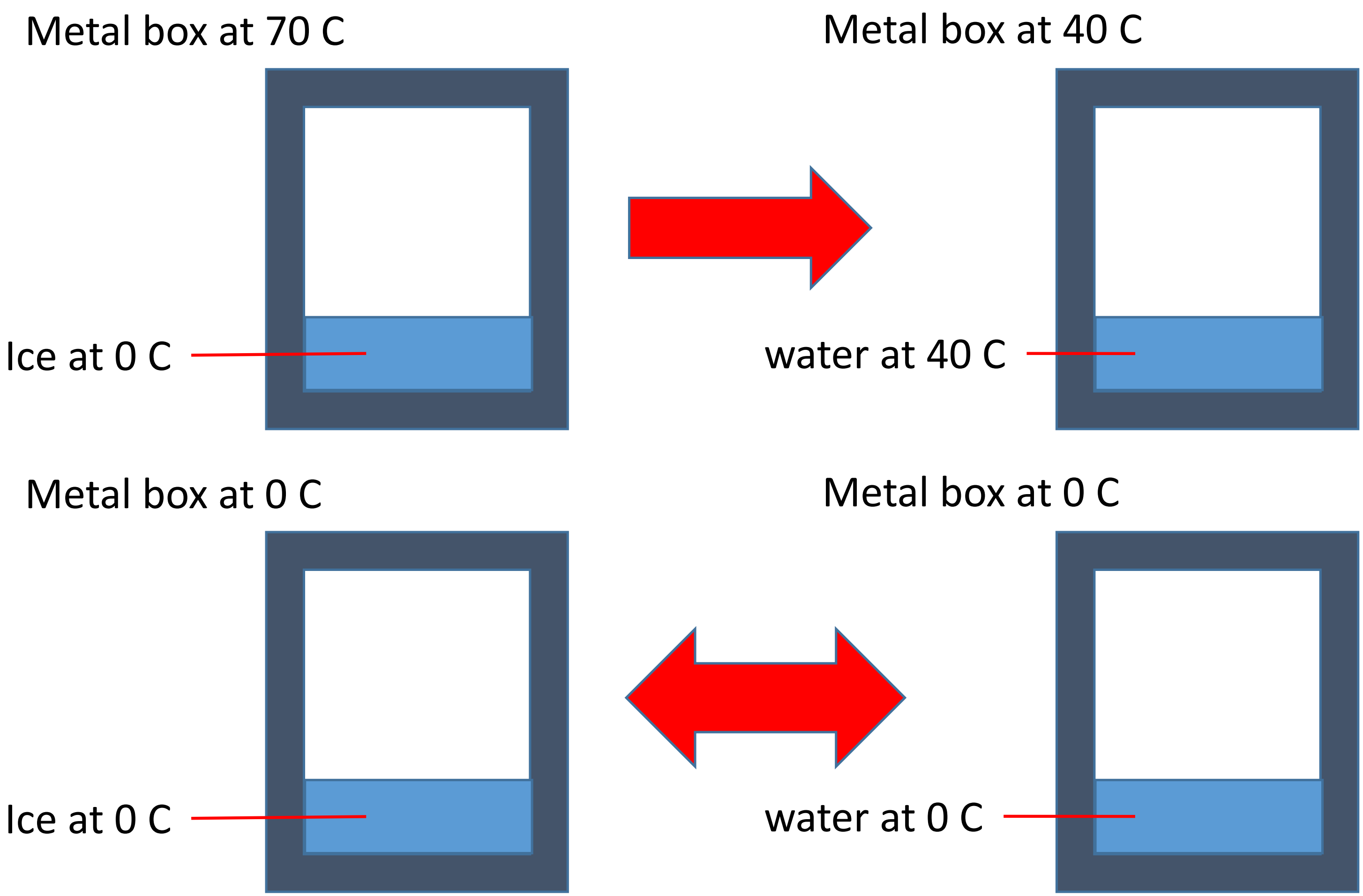
For a process







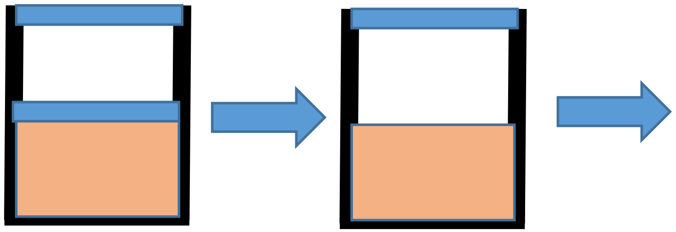
What are “reversible” and “irreversible” processes?



Reversible process: the universe unchanged after the restoration of the process

Free expansion vs isothermal expansion

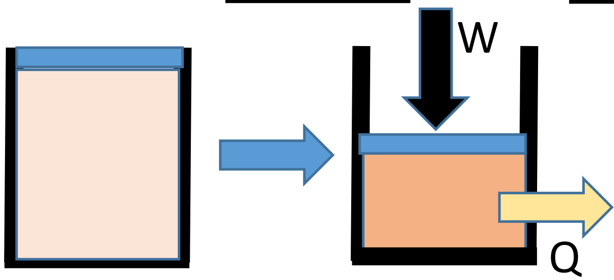
Free expansion (W = 0)



Q = 0, since it is fast

ΔU = 0, by First law

Restoring

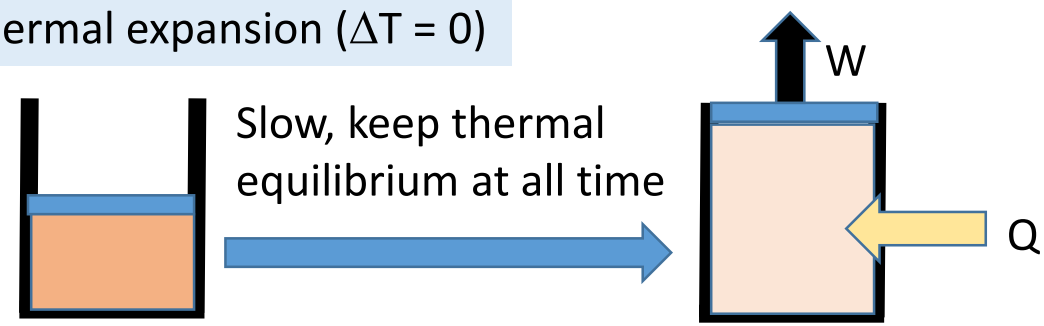


The universe changed (the environment does work to the system and gain heat from it)

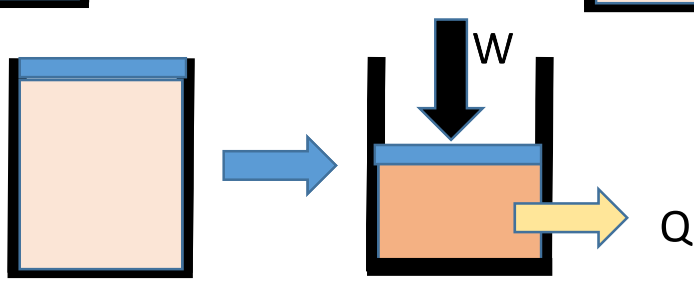
Irreversible

Reversible

Isothermal expansion (ΔT = 0)



Restoring



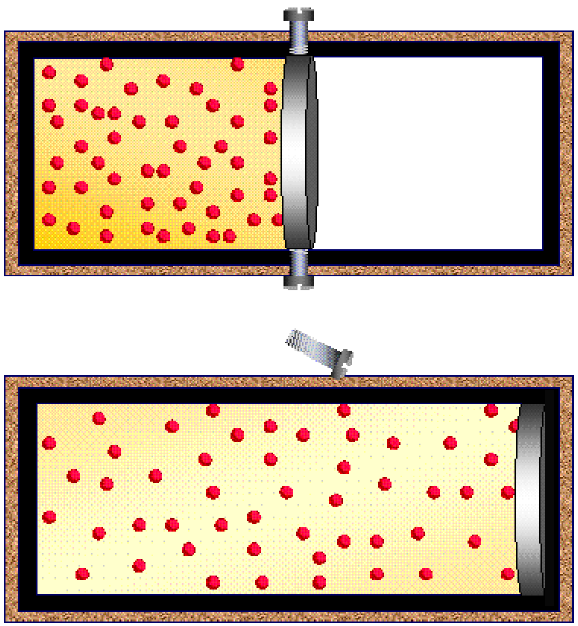
The universe unchanged (W = 0 and Q = 0 for the system and the environment.)

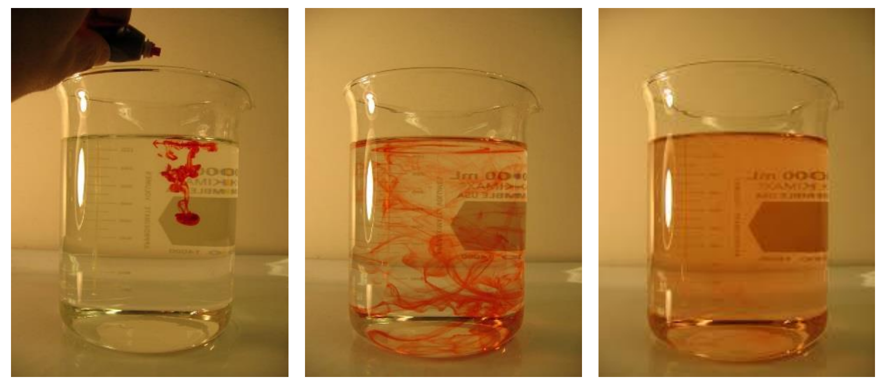
Examples of irreversible process

- Moving object slows down due to friction
- Flow of electric current through a resistance
- Spontaneous mixing of matter of varying composition
- …

How do we compute the change of disorder?

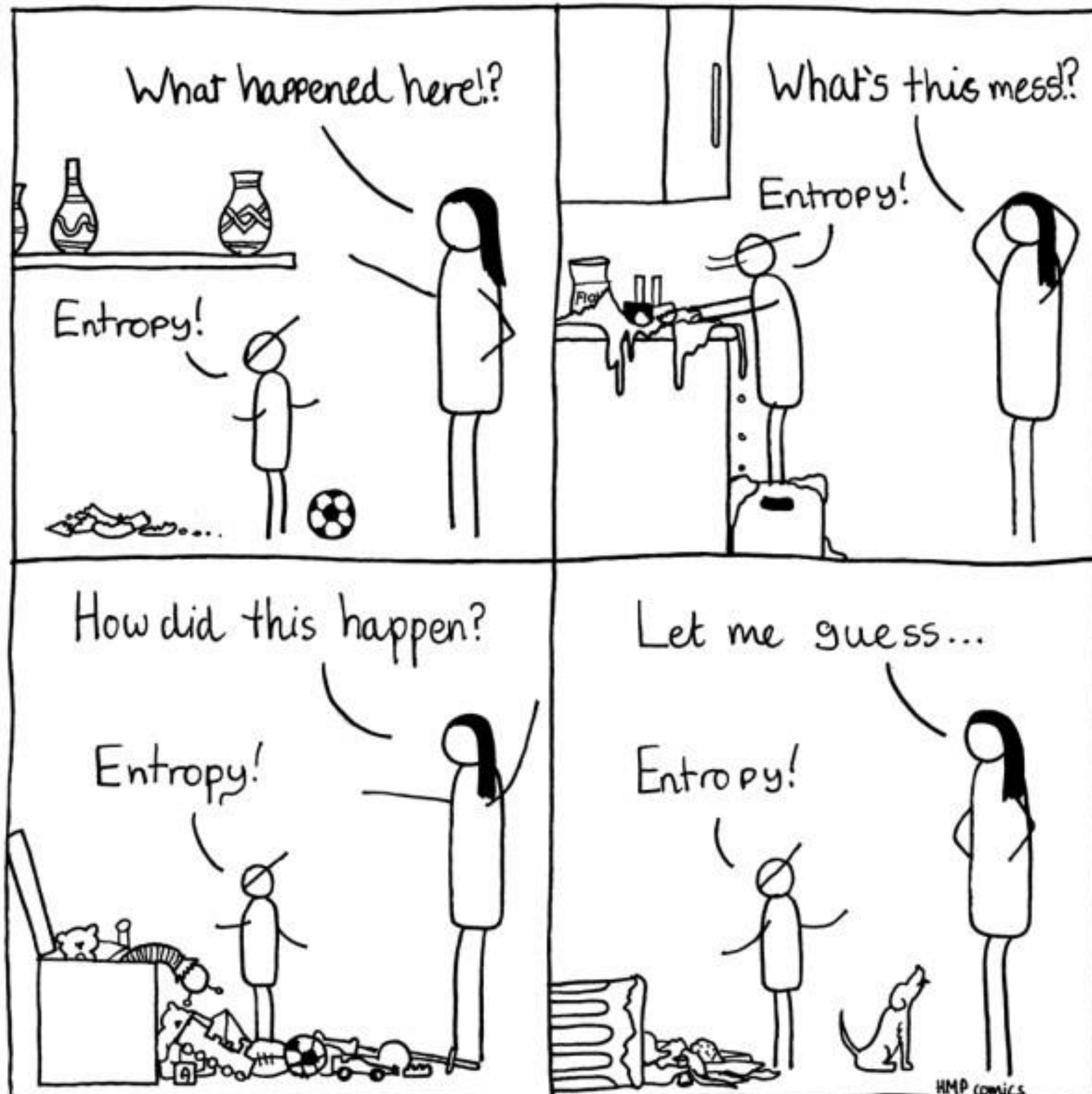
Natural processes tend to increase disorder of the universe.





http://physicsbookanalysis.blogspot.com/

http://people.bu.edu/straub/courses/demomaster/mixingentropy.html



This is why we don't teach our children about entropy until much later...

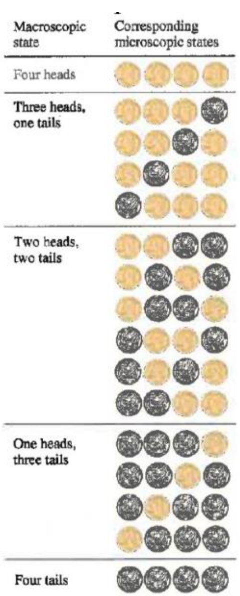
http://comic.hmp.is.it/comic/entropy/

Entropy: A quantity describes level of disorder

$$dS = \frac{dQ}{T}$$

$$\Delta S = \int_1^2 \frac{dQ}{T}$$

Microscopic view of Entropy: calculating the level of disorder



configuration	w	S
4 H	1	$k \cdot ln\ 1$
3 H 1 T	4	$k \cdot ln\ 4$
2 H 2 T	6	$k \cdot ln\ 6$
1 H 3 T	4	$k \cdot ln\ 4$
4 T	1	$k \cdot ln\ 1$

$$S = k \cdot ln\, w$$

w: number of possible state/configuration

The Second Law of Thermodynamics

The Second Law of Thermodynamics: $\Delta S \geq 0$

Reversible process: $\Delta S = 0$

Irreversible process: $\Delta S > 0$

Quiz:

A hot piece of iron is thrown into the ocean and its temperature eventually stabilizes. Which of the following statements concerning this process is correct?

A. The change in the entropy of the iron-ocean system is zero.
B. The ocean gains less entropy than the iron loses.
C. The entropy gained by the iron is equal to the entropy lost by the ocean.
D. The entropy lost by the iron is equal to the entropy gained by the ocean.
E. The ocean gains more entropy than the iron loses.

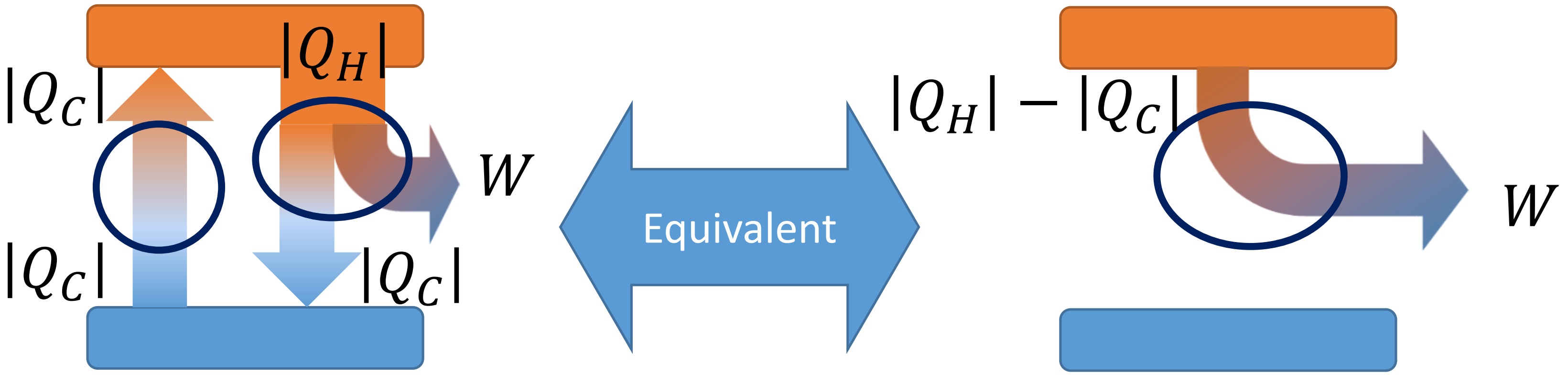
Some process are impossible:
The Second Law of Thermodynamics

Kelvin statement

It is impossible for any system to undergo a process in which it absorbs heat from a reservoir at a single temperature and converts the heat completely into mechanical work, with the system ending in the same state in which it began.

Clausius statement

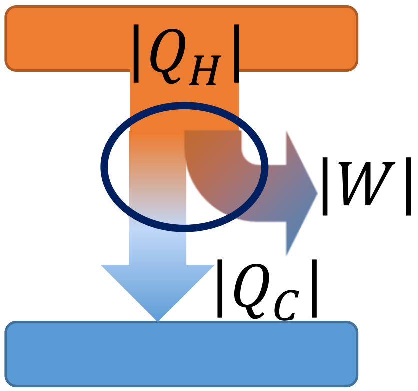
It is impossible for any process to have as its sole result the transfer of heat from a cooler to a hotter body.



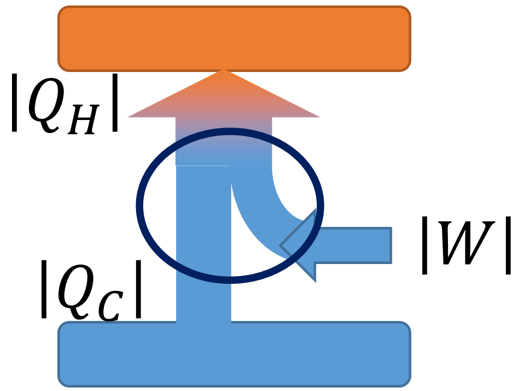
How do we use a heat engine or a refrigerator?

- Both heat engine and refrigerator perform in cyclic processes. In other words, the initial and final states are the same. ➔ ΔU = 0
- During the cycling, some parts of the cycle gain heat, and some lose heat.

$$\Delta U = 0 = Q - W \qquad Q = Q_{in} - Q_{out} = W$$

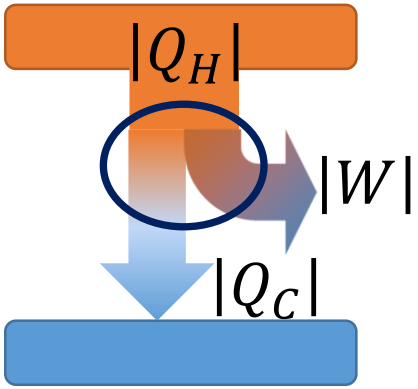


Heat Engine



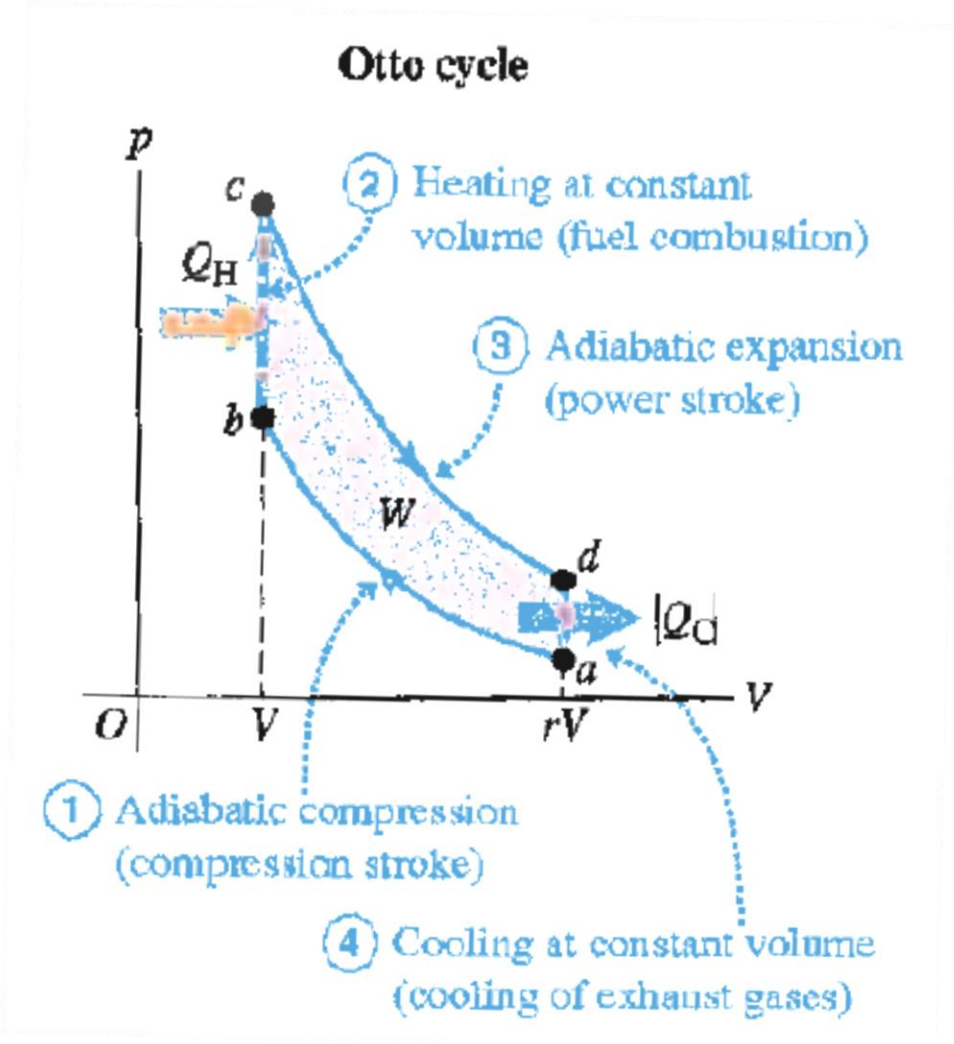
Refrigerator

Heat Engine



Engine efficiency: $e = \frac{W}{|Q_H|}$ $\quad$ $\left(e = \frac{|Q_H| - |Q_C|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}\right)$

Otto Cycle (two adiabatic, and two isochoric processes)



$$e = 1 - \frac{|Q_C|}{|Q_H|}$$

d to *a*

$$\Delta U = U_a - U_d = Q = -|Q_C|$$

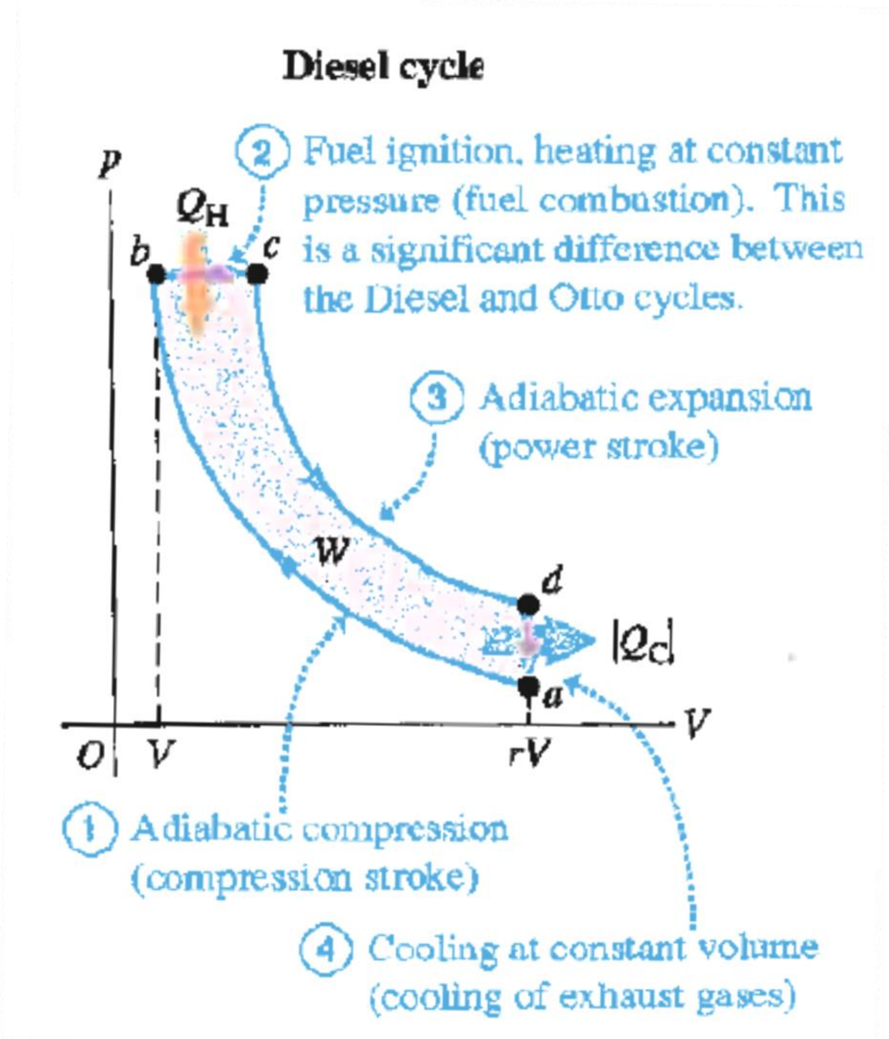
b to *c*

$$\Delta U = U_c - U_b = Q = |Q_H|$$

Note: $\Delta U = nC_V\Delta T$

$$e = 1 - \frac{1}{r^{\gamma-1}}$$

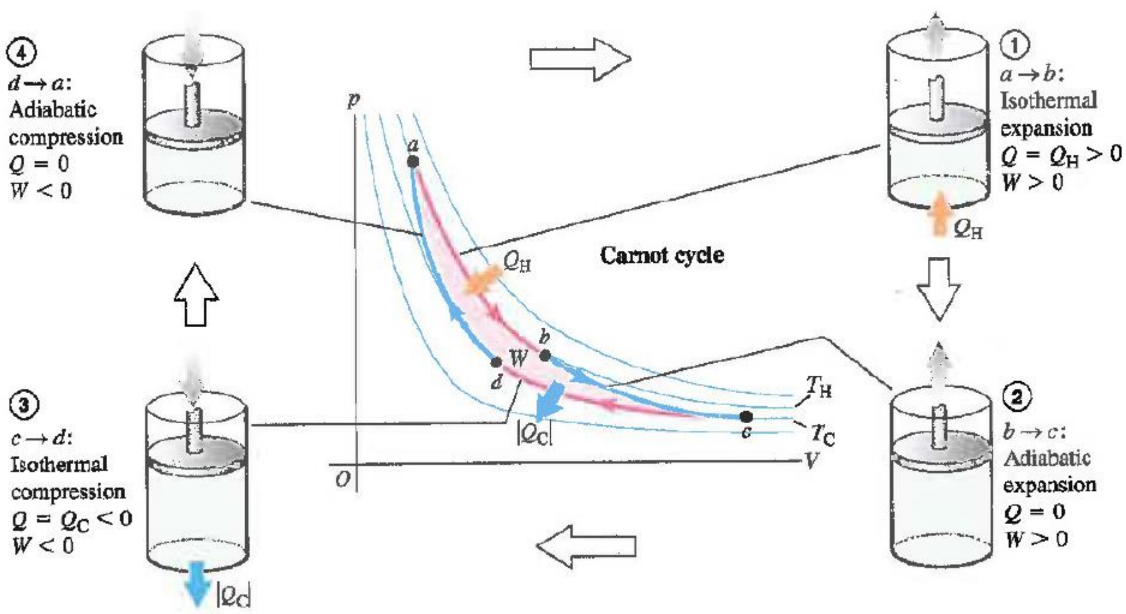
Diesel Cycle (two adiabatic, one isochoric, and one isobaric processes)



Carnot Cycle (two adiabatic, and two isothermal processes)

An ideal cycle that maximize the efficiency

$$e = 1 - \frac{|Q_C|}{|Q_H|}$$



a to *b*

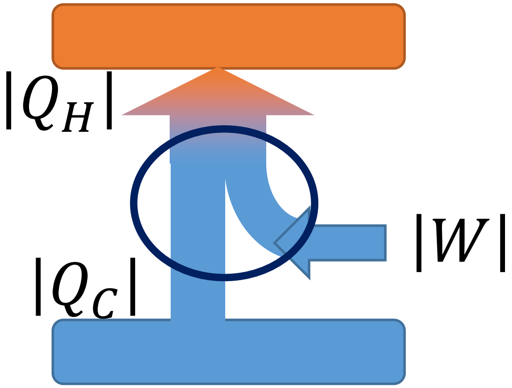
$$Q = |Q_H| = W = \int_a^b p dV$$

c to *d*

$$Q = -|Q_C| = W = \int_c^d p dV$$

$$e = 1 - \frac{T_C}{T_H}$$

Coefficient of performance of refrigerator



Coefficient of performance: $$K = \frac{|Q_C|}{W} = \frac{|Q_C|}{|Q_H| - |Q_C|}$$

$$K = \frac{|Q_C|}{W} = \frac{H}{P}$$

- typical air conditioners have heat removal rates *H* of 5,000 to 10,000 Btu/h (~1,500 – 3,000 W); and require electric power input of about 600 to 1,200 W. Thus, typically, *K* = ~3.