# The Second Law of Thermodynamics

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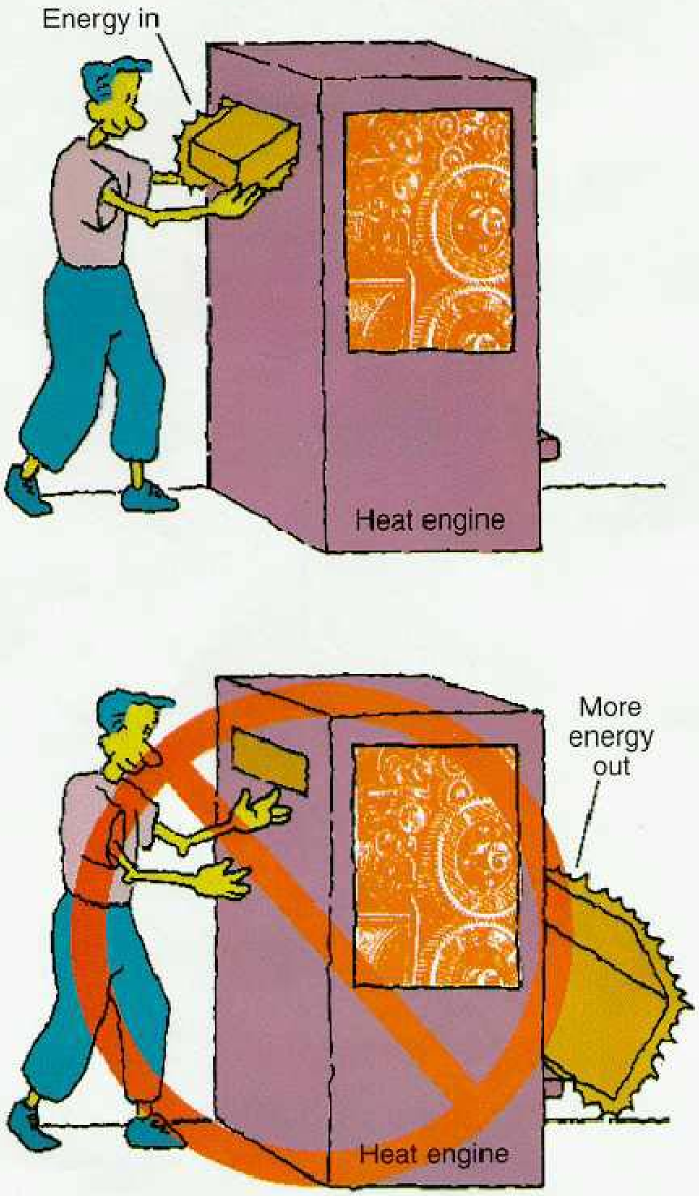
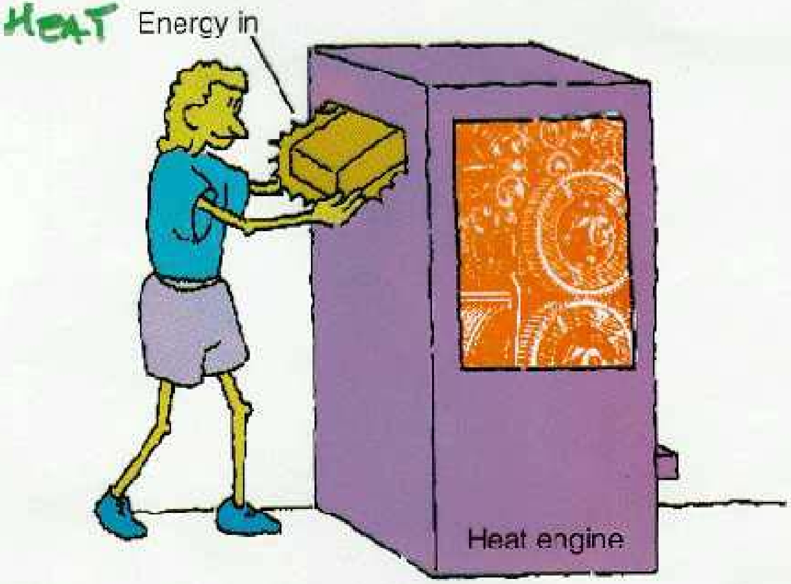
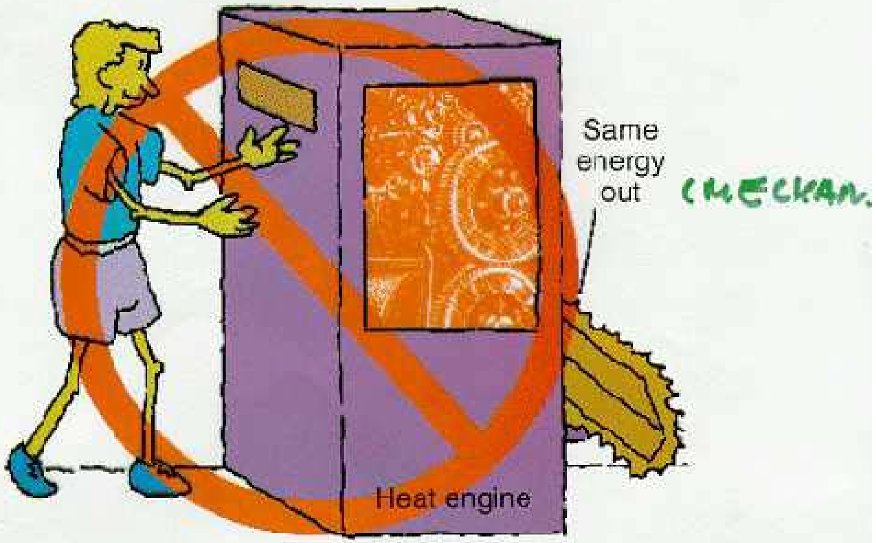


Acetate 8–4 (Figure 8.12)

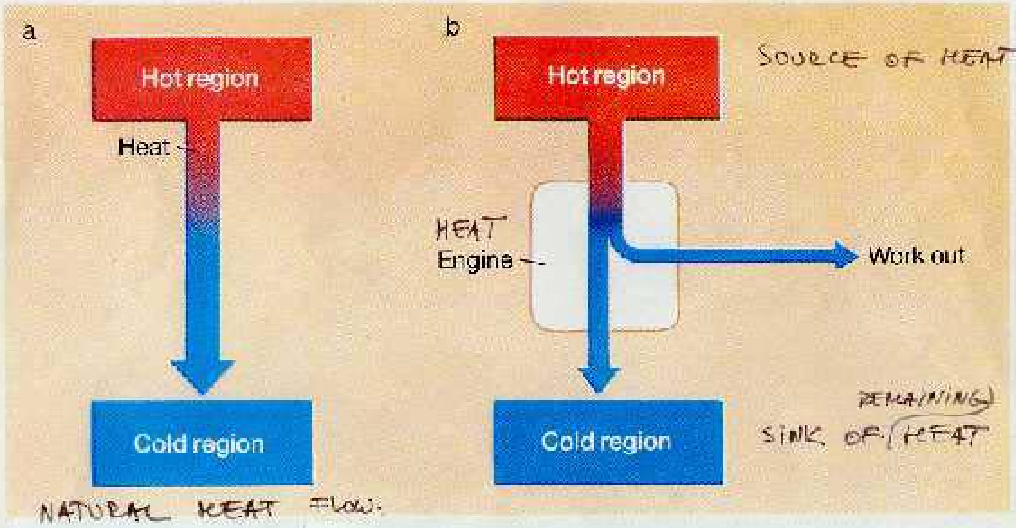
# The Second Law of Thermodynamics





Acetate 8–5 (Figure 8.13)

2)



SOURCE OF HEAT

SINK OF (REMAINING) HEAT

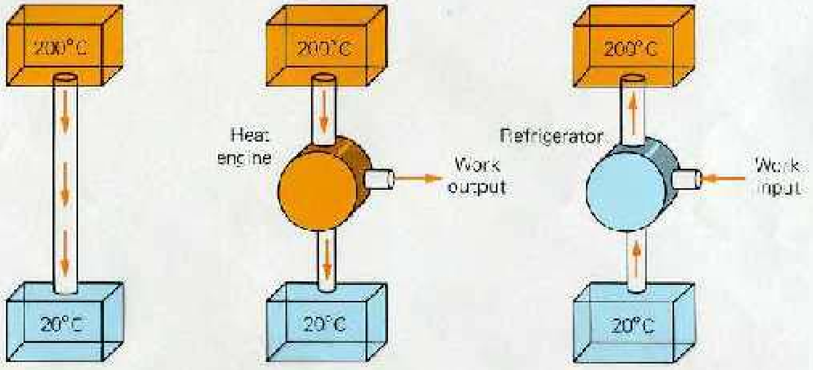
NATURAL HEAT FLOW.

HOT → COLD;
IRREVERSIBLE
PROCESS

(a) Heat naturally flows from a higher temperature region to a lower temperature region. (b) A heat engine extracts part of the thermal energy to perform mechanical work and exhausts the remaining thermal energy.

26. **Figure 10.6,** Kirkpatrick/Wheeler

Figure 4-29

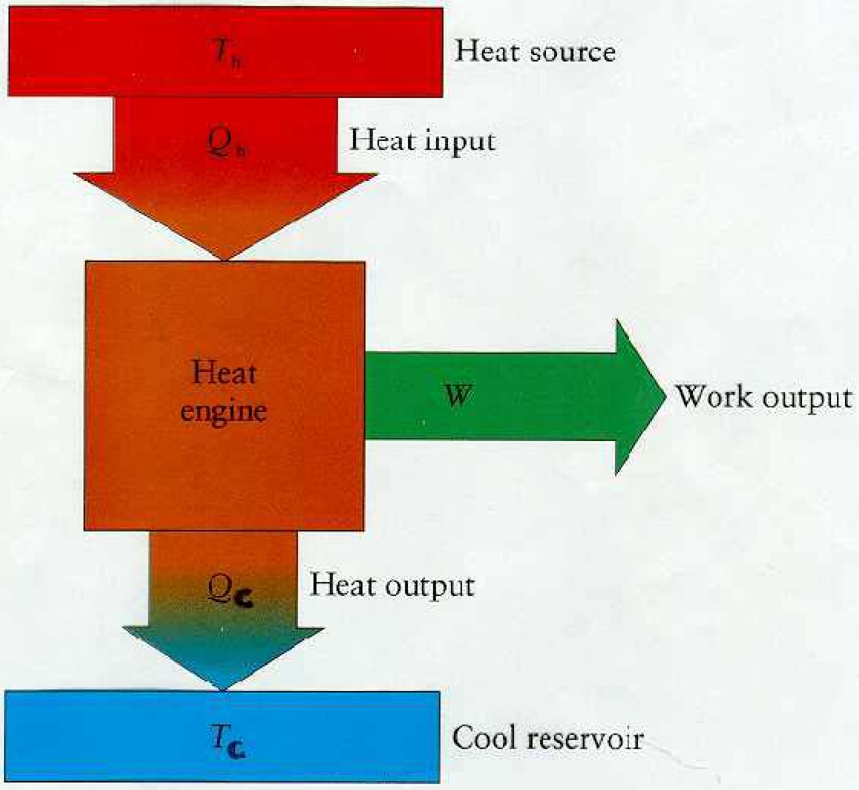


Heat flows by itself from a hot reservoir to a cold reservoir.

Part of the flow of heat can be converted into work by a heat engine.

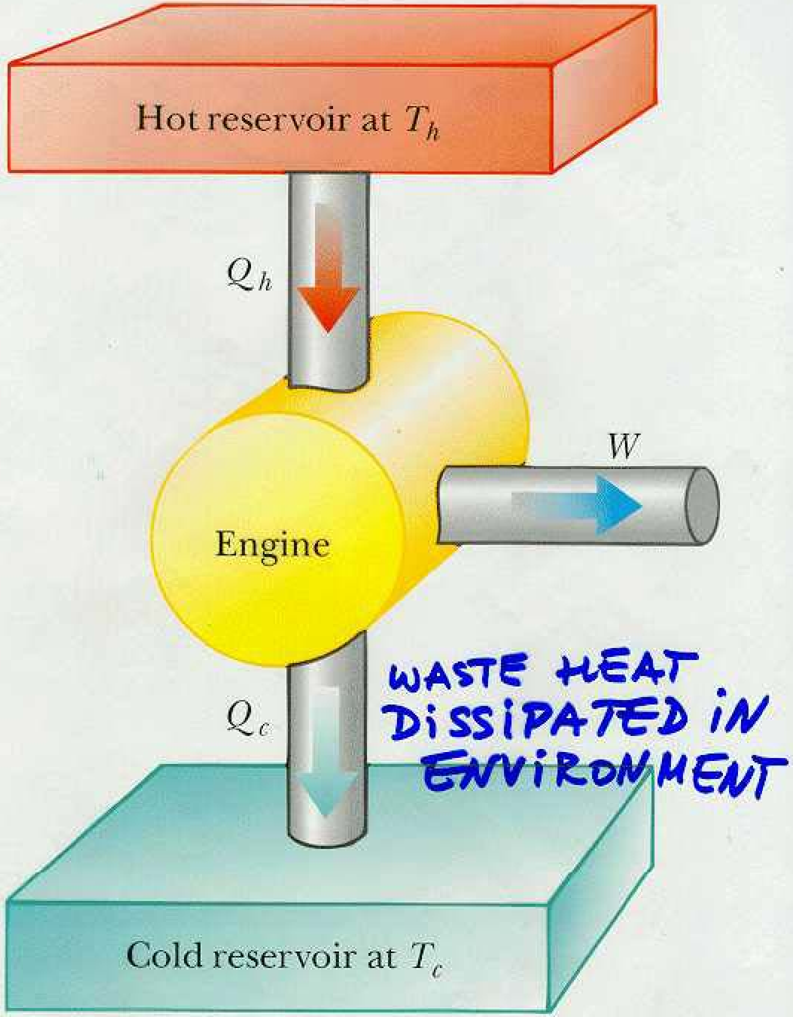
To reverse the natural flow of heat, work must be done by a refrigerator.

## Diagram of a Heat Engine



Acetate 69 (Figure 5.33)

5)



WASTE HEAT DISSIPATED IN ENVIRONMENT

Overhead transparencies to accompany Serway/Faughn: *College Physics, 4/e*
Figure 59 Text figure 12.6 page 361
Schematic representation of a heat engine

5')

Transparency 59

Figure 16.18 Page 664

## A Heat Engine

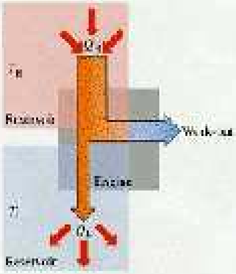
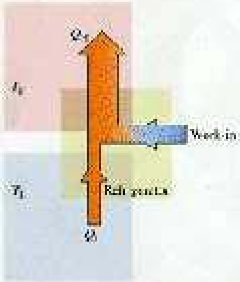


Figure 16.19 Page 666

## A Waterfall Analogy for a Heat Engine

Figure 16.22 Page 667

## A Refrigeration Machine



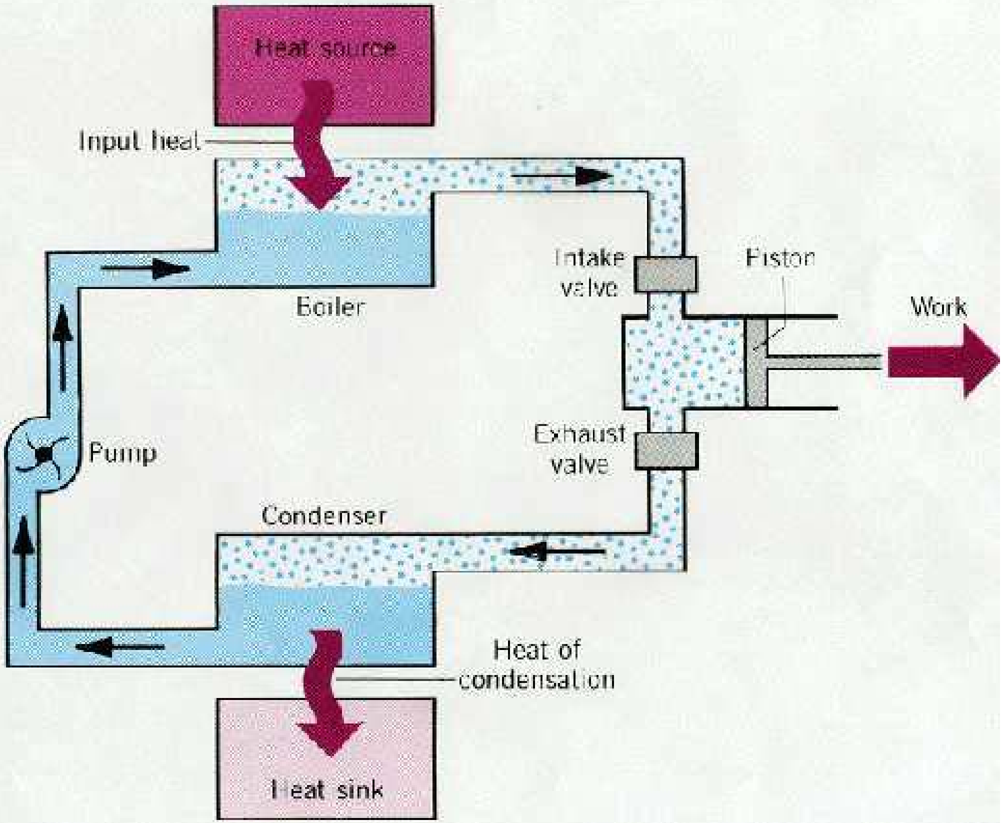
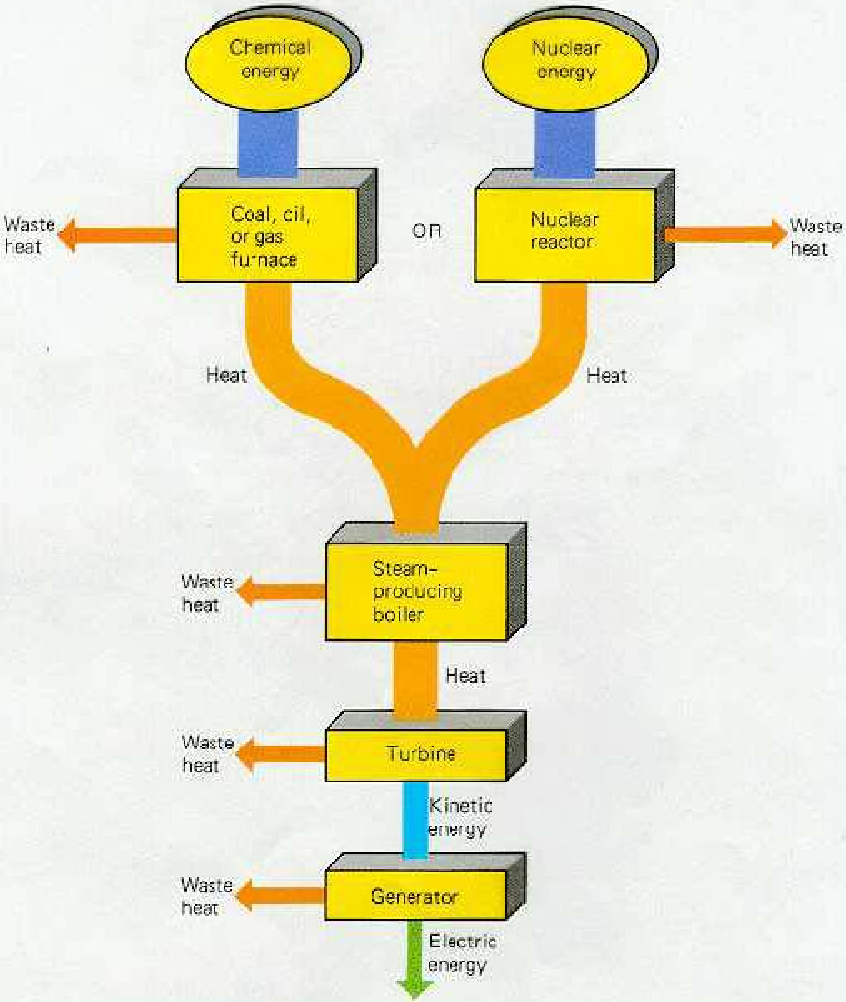

Heat source
Input heat
Boiler
Intake valve
Piston
Work
Pump
Exhaust valve
Condenser
Heat of condensation
Heat sink

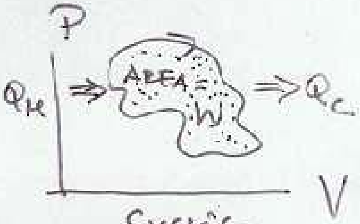
FIGURE 15.11

**Figure 4-32**

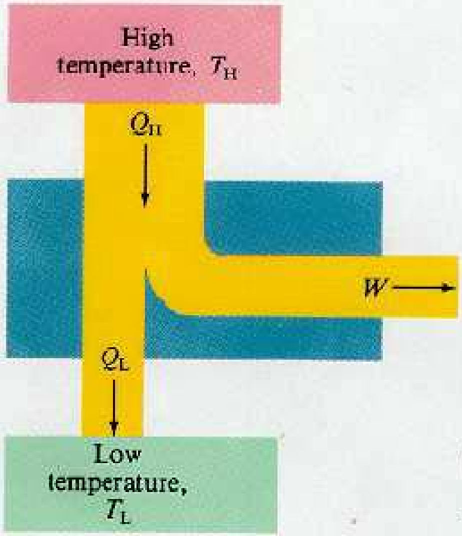

Chemical energy
Nuclear energy
Waste heat
Coal, oil, or gas furnace
or
Nuclear reactor
Waste heat
Heat
Heat
Waste heat
Steam-producing boiler
Heat
Waste heat
Turbine
Kinetic energy
Waste heat
Generator
Electric energy

7)

**FIGURE 15–6** Schematic diagram of a heat engine.



Cyclic process for a gas



MECHANICAL WORK DONE

PERPETUAL MACHINE 1st KIND: 0 → ENERGY

A WORKING SUBSTANCE (AIR-FUEL MIXTURE, STEAM, ETC.) IS CARRIED THROUGH A CYCLIC PROCESS AND RETURNS TO THE INITIAL STATE AFTER EVERY CYCLE:

$\Delta U_{cycle} = 0 \Rightarrow$ 1st LAW: $Q_{NET} = W$,

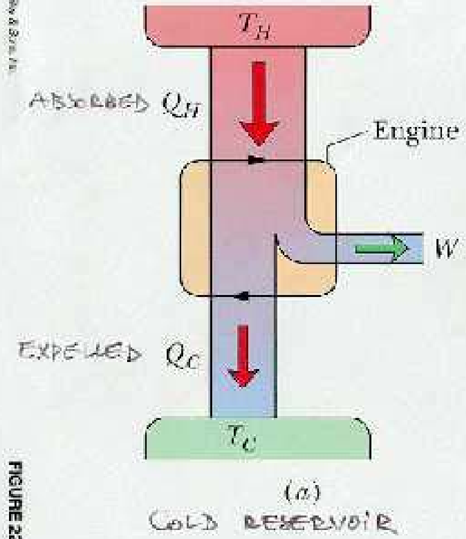
$Q_{NET} = Q_H - |Q_C|$, AND

$\underline{Q_H = W + Q_C}$ ENERGY CONSERV.

3) $\Delta U = Q - W$

GIANCOLI'S PHYSICS:
PRINCIPLES WITH APPLICATIONS, 3/E

THERMAL EFFICIENCY $$e \equiv \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H} < 1$$
for $Q_C \neq 0$.



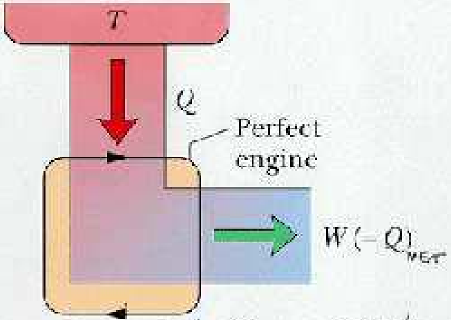
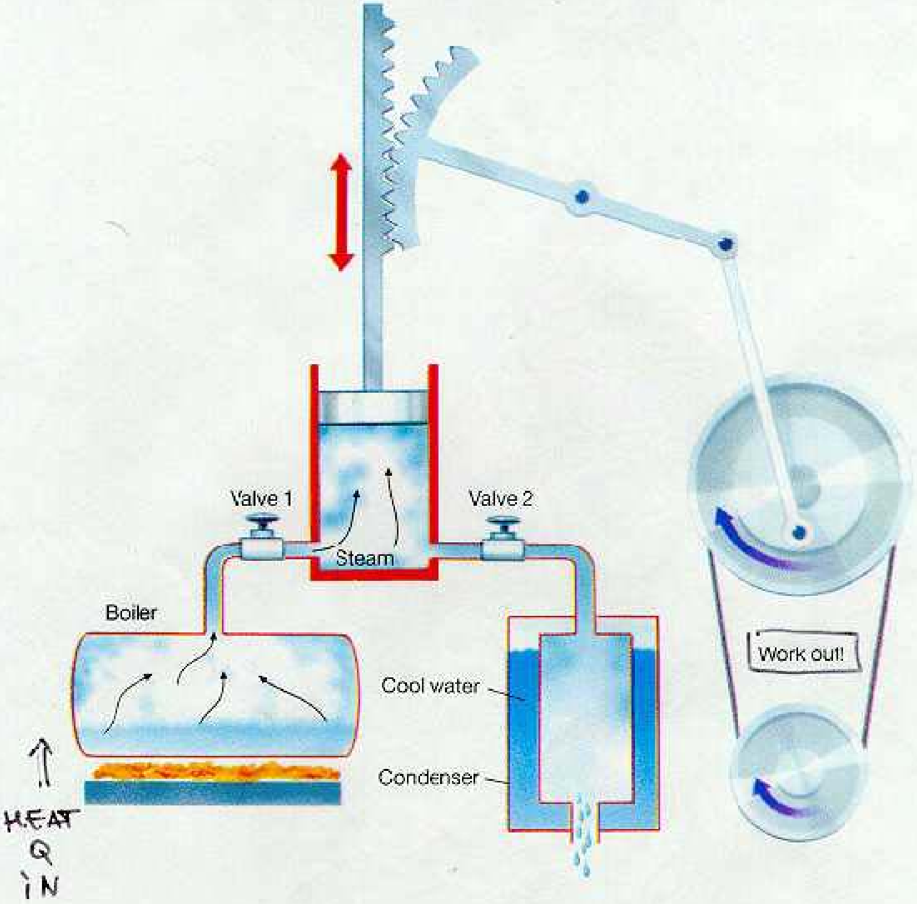


FIGURE 22.2

$e_{CAR} \simeq 20\%$, $e_{DIESEL} \simeq 35\%$ ⇒ ietc.
⇒ ALL HEAT ENGINES
HAVE $e < 1$, or $e < 100\%$

II LAW OF THERMODYNAMICS:
IT IS IMPOSSIBLE TO CONSTRUCT A CYCLIC HEAT ENGINE CONVERTING ALL ITS ABSORBED THERMAL ENERGY INTO WORK:
$$e < 1$$

# THE WATT'S STEAM ENGINE



The essential features of Watt's steam engine.

10)

27. **Figure 10.3,** Kirkpatrick/Wheeler

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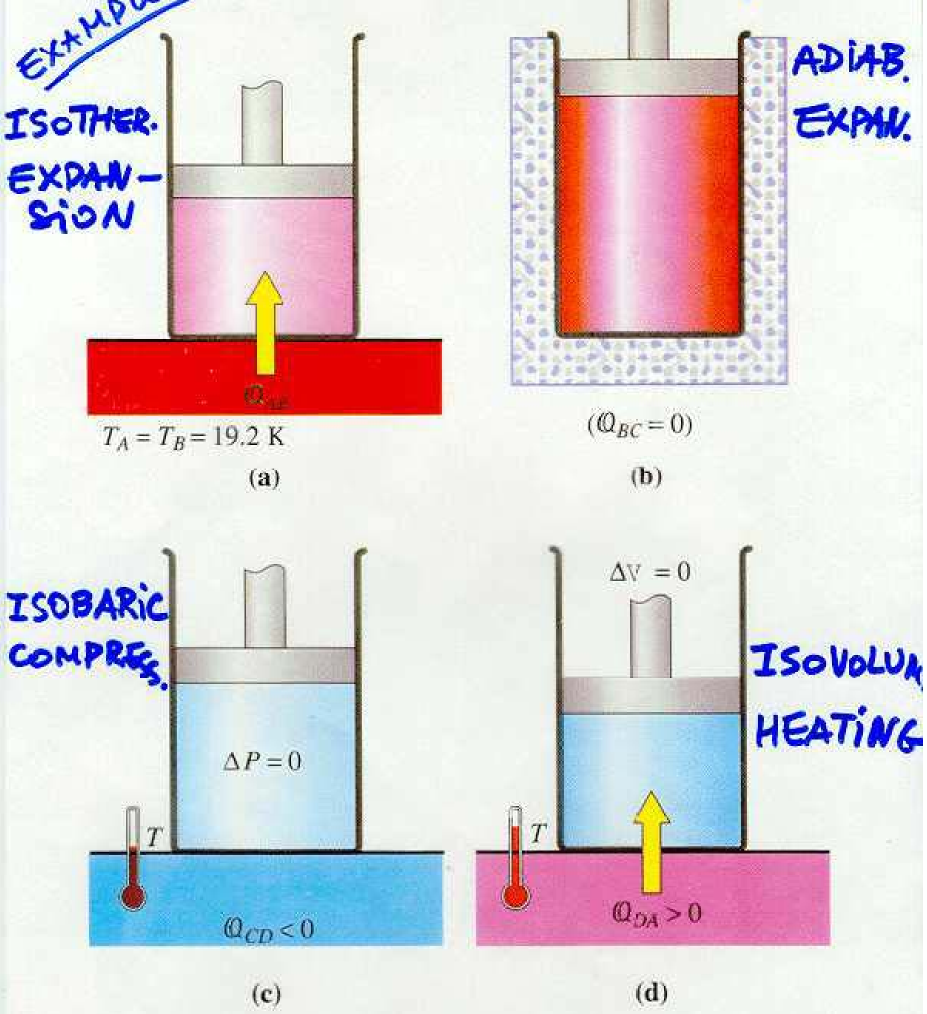
# THE PHYSICS TEACHER'S CYCLE



$T_A = T_B = 19.2$ K

(a)

($Q_{BC} = 0$)

(b)

(c)

(d)

66 **Piston Model**
Figure 19.14

26) 10')

Crummett, William P. and Western, Arthur B. *University Physics: Models and Applications.*

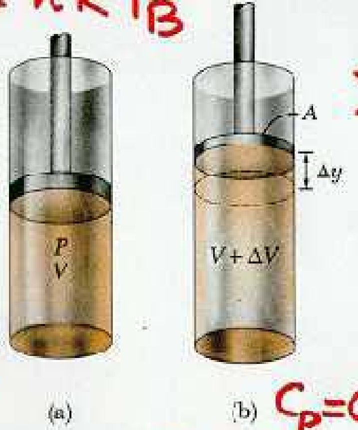
FIND $P_B, V_B$: ON BC (ADIAB.) $P_B V_B^{\gamma} = P_C V_C^{\gamma}$;

AT B: $P_B V_B = nRT_B$

2 EQS FOR 2 UNKNOWNS:

$P_B = 3.51\times10^{4}$ PA

$V_B = 4.55\times10^{-3}\,m^3$



(a) (b)

Fig. 13-1

He: f = 3

$\gamma = 5/3$

$C_V = \frac{f}{2}R = \frac{3}{2}R =$

$= 12.5 \frac{J}{mol\cdot K}$

$C_p = C_V + R = 20.8\,J/mol\,K$

WE NOW HAVE P, V, T AT EACH VERTEX.

FIND Q, W, ΔU:

ISOTHERM A→B:

$W_{AB} = nRT_A \ln\frac{V_B}{V_A} =$

$= 1\times8.3\times19.2\times\ln\frac{4.55}{2}$

$= 132\,J$;

$\Delta U_{AB} = 0$, SO

(I LAW: 0 = Q − W)

$Q_{AB} = W_{AB} = 132\,J$

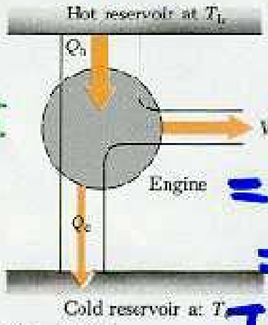


Fig. 13-6

ADIABAT B→C:

$Q_{BC} = 0$;

$\Delta U_{BC} = nC_V(T_C - T_B)$

$= 1\times12.5\times(18-19.2)$

$= -15\,J$;

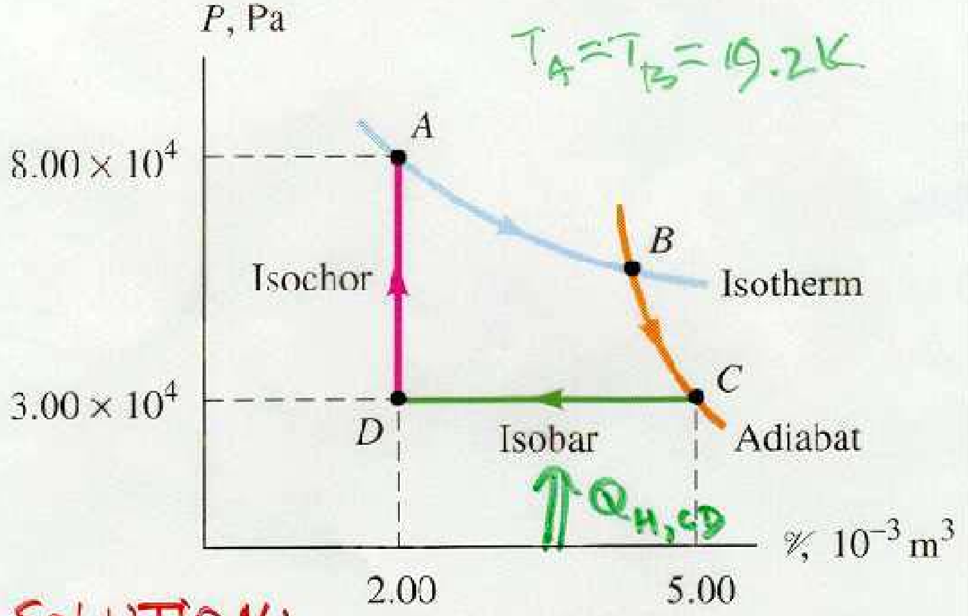
I LAW: $\Delta U = 0 - W$

$W_{BC} = +15\,J$

COMPUTE $\Delta U$, Q AND W FOR EACH PORTION OF THE CYCLE AND THEIR TOTALS FOR THE CYCLE.

GIVEN: $P_A, P_D = P_C, V_A = V_D, V_C$

1 MOLE OF HELIUM (IDEAL), monoatomic



SOLUTION:

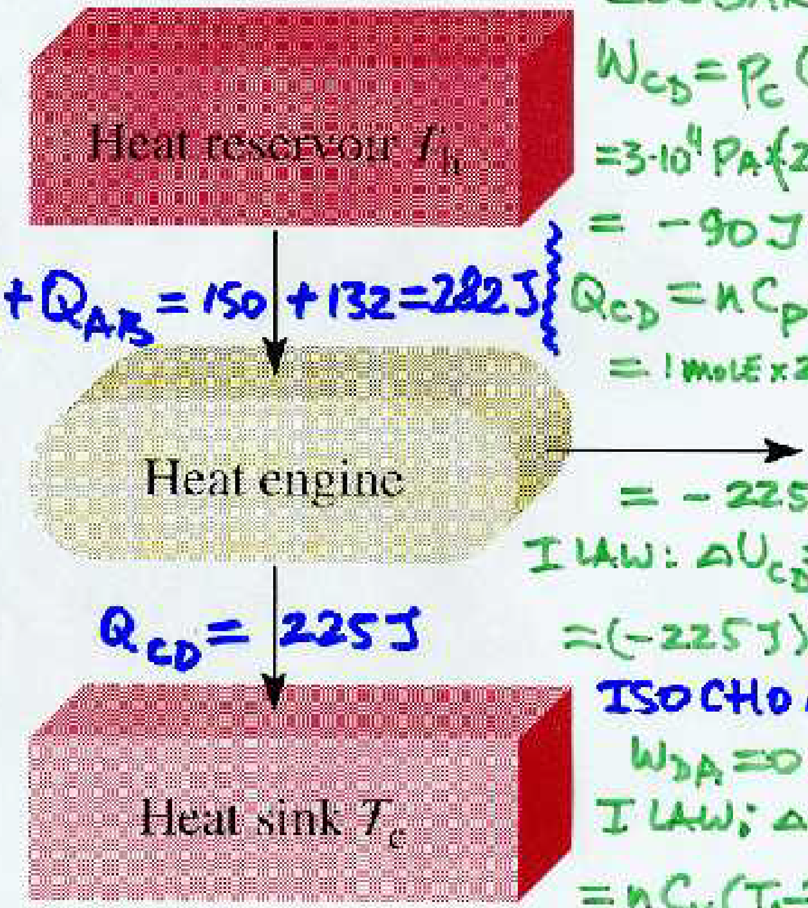
$$T_B = T_A = \frac{P_A V_A}{nR} = \frac{8\times10^4 P_A \times 2\times10^{-3} M^3}{1\ MOLE \times 8.3\ J/MOLE \cdot K} = 19.2\ K$$

Simil. $T_C = P_C V_C / nR = 18.0\ K$

$T_D = P_D V_D / nR = 7.22\ K$

65 The Physics-Teachers' Cycle
Figure 19.13

27) (10")



$Q_{DA} + Q_{AB} = 150 + 132 = 282\,J$

$Q_{CD} = 225\,J$

Figure 19.6

ISOBAR C→D:

$W_{CD} = P_C (V_D - V_C) =$

$= 3\cdot10^4\,PA \times (2\cdot10^{-3}\,m^3 - 5\cdot10^{-3}\,m)$

$= -90\,J$

$Q_{CD} = nC_p\Delta T = n\cdot\frac{5}{2}R(T_D - T_C)$

$= 1\,\text{mole} \times 20.8\,\frac{J}{\text{mol}\cdot K} \times (7.2 - 18)K$

$= -225\,J.$

I LAW: $\Delta U_{CD} = Q_{CD} - W_{CD} =$

$= (-225\,J) - (-90\,J) = -135\,J.$

ISOCHOR D→A:

$W_{DA} = 0$ (V = CONST)

I LAW: $\Delta U_{DA} = Q_{DA} - 0 =$

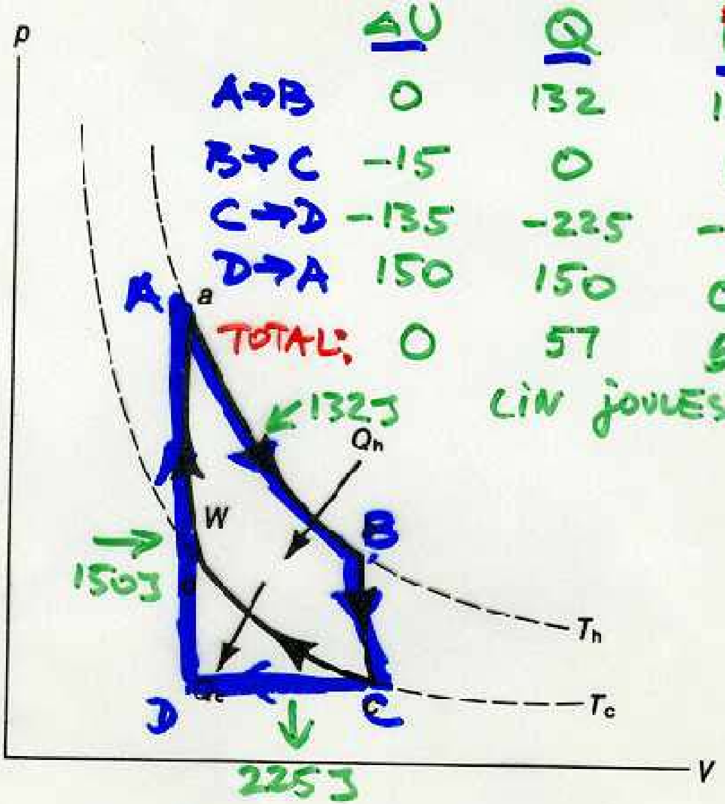
$= nC_V(T_A - T_D) = n\frac{3}{2}R\cdot\Delta T =$

$= 1\,\text{mol} \times 12.5\,J/\text{mol}\cdot K \times (19.2 - 7.2) = 150\,J.$

# SUMMARY:

| | $\Delta U$ | $Q$ | $W$ |
|---|---|---|---|
| A→B | 0 | 132 | 132 |
| B→C | −15 | 0 | 15 |
| C→D | −135 | −225 | −90 |
| D→A | 150 | 150 | 0 |
| TOTAL: | 0 | 57 | 57 |

(in joules).



Efficiency:

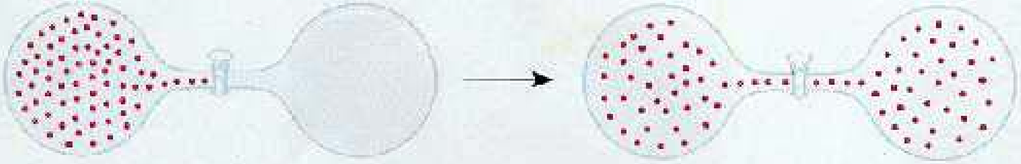
Figure 22-7

$$e = \frac{W}{Q_H} = \frac{W(\text{cycle})}{Q_{AB}+Q_{DA}} = \frac{57}{132+150} =$$

$$= \frac{57}{282} \simeq 0.20 = 20\%$$

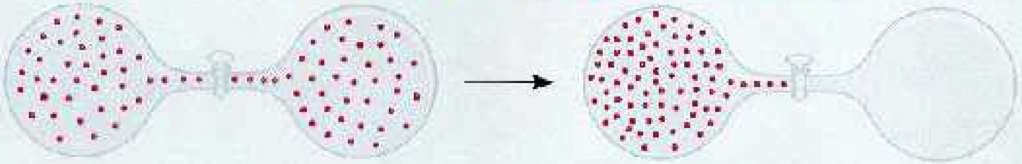
30) $10\frac{V}{J}$

## A SPONTANEOUS PROCESS



(a)

## A NON-SPONTANEOUS PROCESS

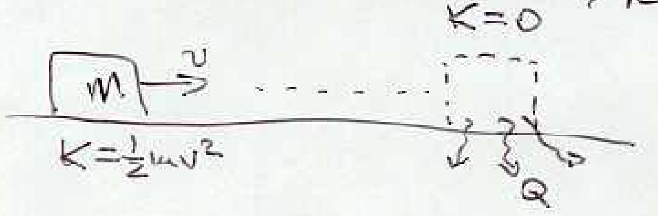


(b)

## IRREVERSIBLE

EACH ELASTIC COLLISION CAN BE RUN BACKWARDS AS AN EQUALLY POSSIBLE PROCESS; BUT THE CHANCE OF THE MOLECULES TO SPONTAN. COLLECT IN LEFT TANK ≈ 0.

PHYSICAL PROCESSES → IRREVERSIBLE
→ REVERSIBLE



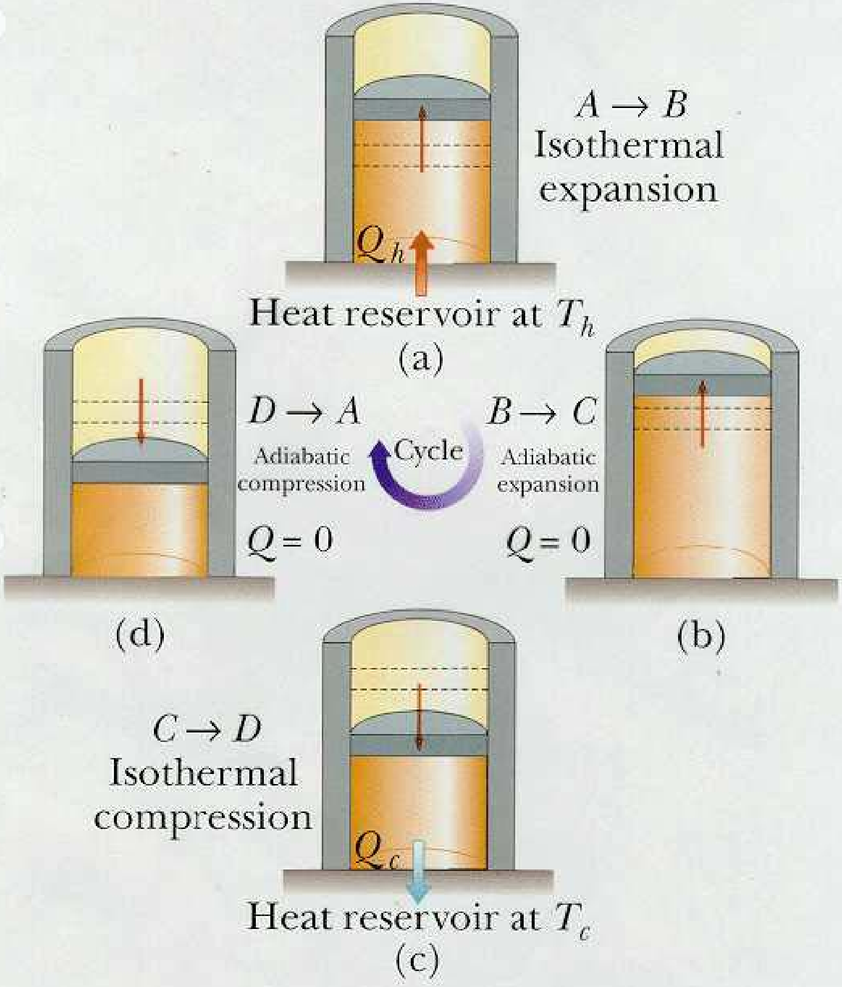
$K \underset{\cancel{\longleftarrow}}{\longrightarrow} Q$
IRREVERS.

REVERSIBLE:

- QUASI-STATIC (EQUIL. STATES)
- NO DISSIPATION OF MECH. ENERGY TO HEAT (NEGLIGIBLE FRICTION)
- NO HEAT CONDUCTION WITH FINITE $\Delta T \neq 0$

CAN BE REPRESENTED ON P-V DIAGRAM; IRREVERSIBLE - CAN NOT (NO DEFINITE UNIQUE P).

# THE CARNOT CYCLE



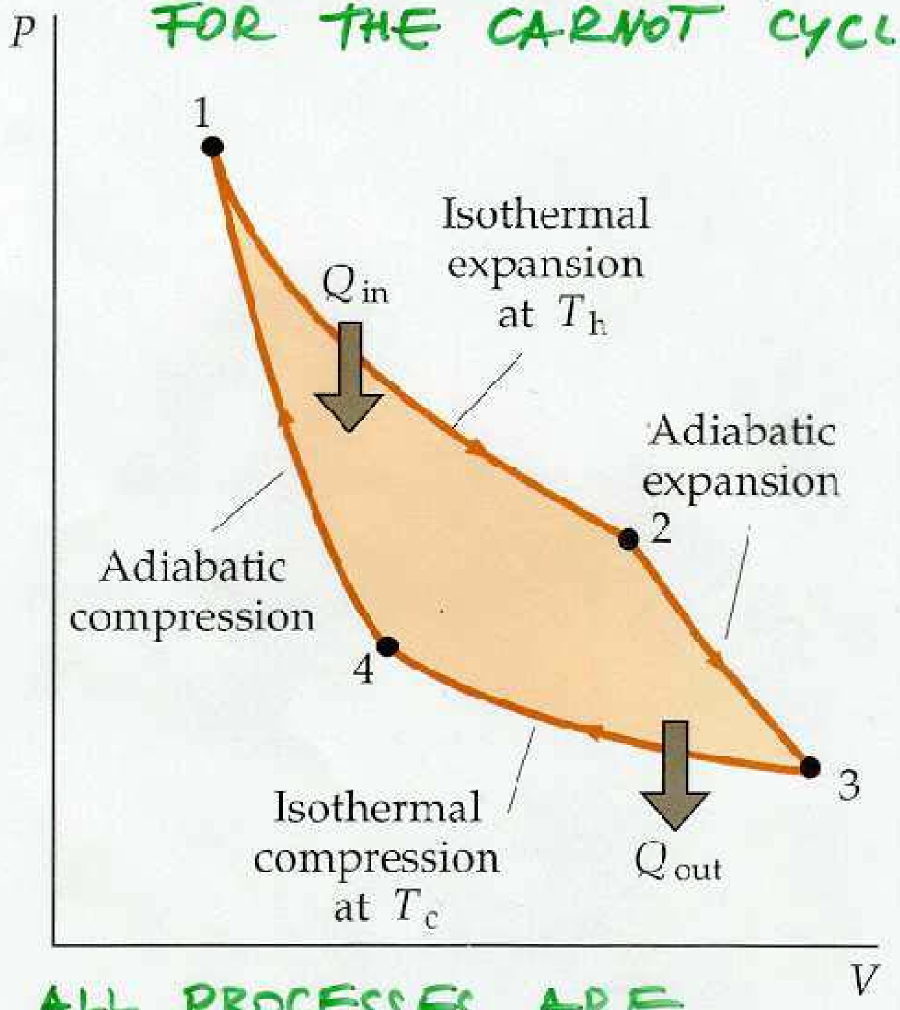
Overhead transparencies to accompany Serway/Faughn: *College Physics, 4/e*
Figure 60 Text figure 12.10 page 365
The Carnot cycle

13)

*Transparency 75*
Figure 17-9, page 571
A Carnot cycle for an ideal gas

Tipler: Physics for Scientists and Engineers
Third Edition, Volume 1

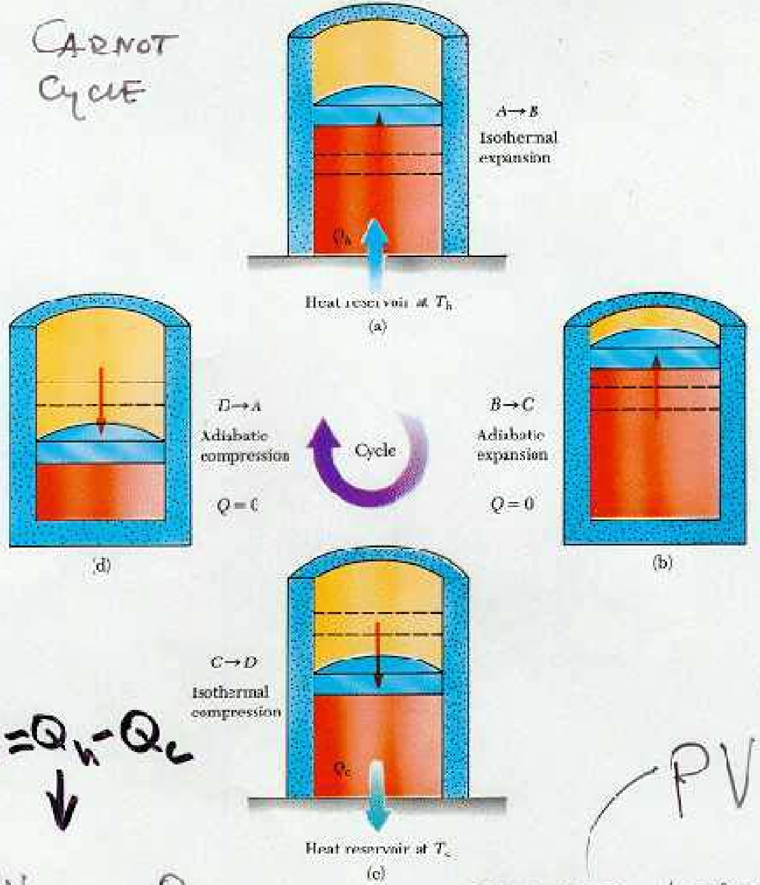
THE P-V DIAGRAM
FOR THE CARNOT CYCLE



ALL PROCESSES ARE
REVERSIBLE

14)

CARNOT CYCLE



$$W = Q_h - Q_c$$

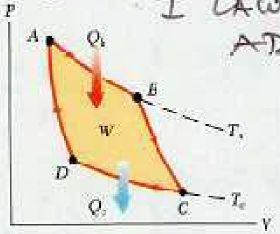
↓

$$PV^{\gamma} = \text{cons}$$

$$e \underset{\text{def}}{=} \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

↑ I LAW

; FOR CARNOT (USING I LAW, IDEAL GAS AND ADIABATIC EQS)



$$\frac{Q_c}{Q_h} = \frac{T_c}{T_h} \Longrightarrow$$

$$\boxed{e_{\text{CARNOT}} = 1 - \frac{T_c}{T_H}}$$

64. Serway Fig. 22.8, Fig. 22.9

EXAMPLE:

PV CARNOT DIAGRAM

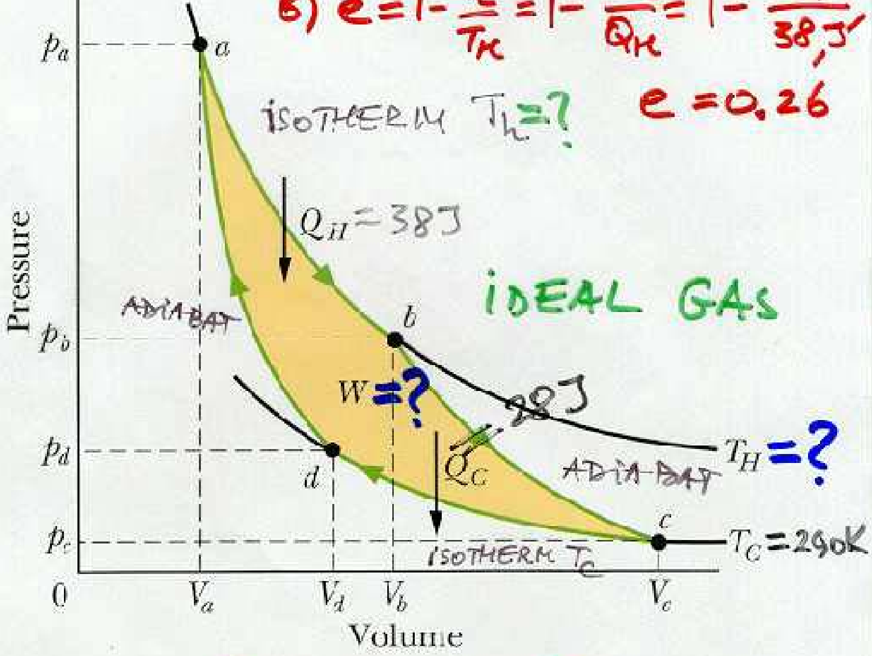
FIND WORK, efficiency AND $T_H$.

a) $W = \oint P dV$ OR I LAW: $0 = (Q_H - Q_c) - W$

$W = 38J - 28J = 10J.$

b) $e = 1 - \frac{T_c}{T_H} = 1 - \frac{Q_C}{Q_H} = 1 - \frac{28J}{38J}$

$e = 0.26$



c) $e = 1 - \frac{T_c}{T_H} \Rightarrow e - 1 = -T_c/T_H \Rightarrow$

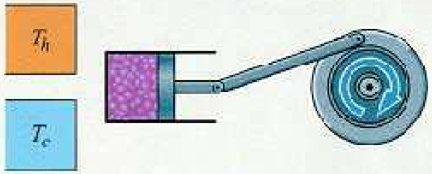
$T_H(1-e) = T_C \Rightarrow T_H = \frac{T_c}{1-e} =$

$= \frac{290K}{1-0.26} = 390K$

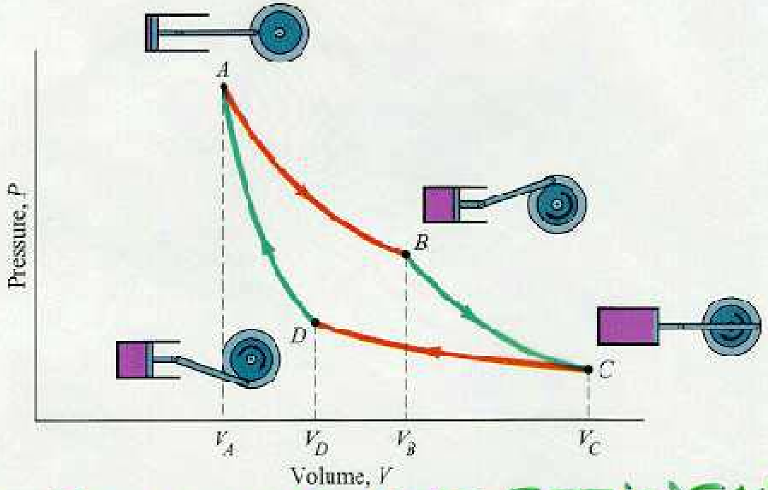
(6)

FIGURE 22-9

# THE IMPORTANCE OF THE CARNOT ENGINE:



1. $e = 1 - T_C/T_H$, EVEN IF GAS IS NOT IDEAL - ANY FLUID CAN BE USED; OTHERWISE, II LAW WOULD BE VIOLATED.



2. IT IS THE MOST EFFICIENT ENGINE POSSIBLE OPERATING BETWEEN GIVEN $T_H, T_C$

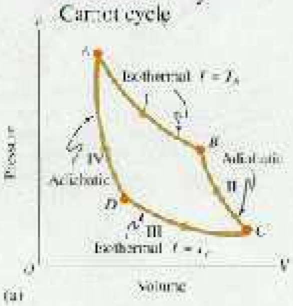
Figures 22-5, 22-6
*Physics for Scientists and Engineers,* Second Edition
by Richard Wolfson and Jay M. Pasachoff

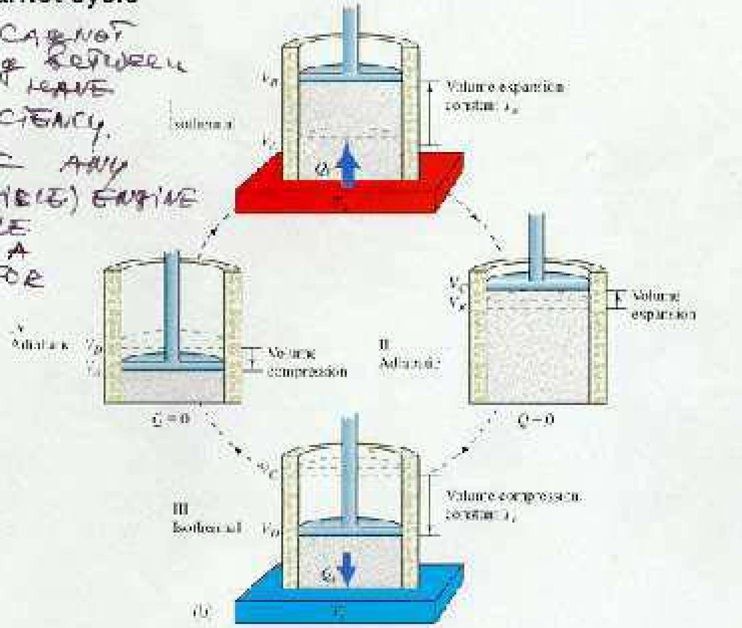
17)

# T73 (Figure 20-4) The Carnot cycle

1. ALL REVERSIBLE CARNOT ENGINES WORKING BETWEEN THE SAME $T_C, T_H$ HAVE THE SAME EFFICIENCY.

2. EFFICIENCY OF ANY REAL (IRREVERSIBLE) ENGINE IS LESS THAN THE EFFICIENCY OF A CARNOT ENGINE FOR SAME $T_C, T_H$.





PHYSICS FOR SCIENTISTS
AND ENGINEERS
by Fishbane/Gasiorowicz/Thornton

$$e_{REAL} < e_{CARNOT} < 1$$

$e_C = 1 - \frac{T_C}{T_H} = 100\%$ only for $T_C = 0$
– IMPOSSIBLE!

# CARNOT ENGINE AS THERMOMETER:

IDEAL GAS TEMP. SCALE:

V=CONST GAS THERMOMETER.

$$T = \lim_{m \to 0} \frac{P}{P_3} 273.16$$

WITH THE CARNOT ENGINE RUN BETWEEN A SYSTEM OF UNKNOWN TEMP. T AND A TRIPLE CELL OF WATER WITH ITS TEMP. DEFINED TO BE $T_3 = 273.16$, WE CAN USE THE RELATION

$$\frac{T}{T_3} = \frac{Q}{Q_3}$$

TO DEFINE

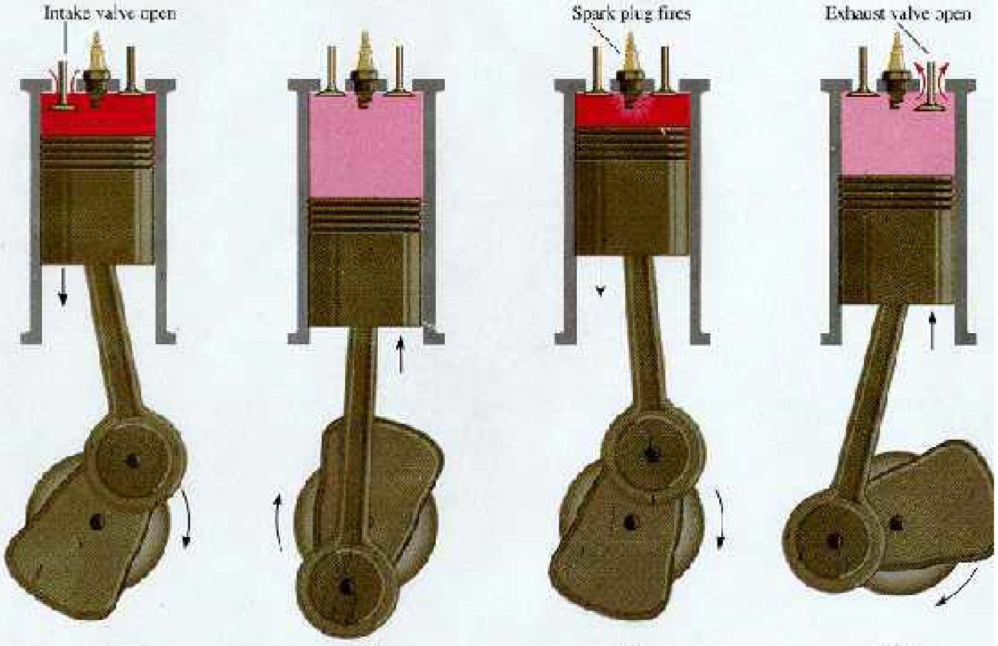
ABSOLUTE TEMP. SCALE

$$T \underset{DEF}{=} 273.16K \frac{Q}{Q_3} \text{ —}$$

INDEP. OF WORKING SUBSTANCE, VALID AT V. LOW TEMPERAT. (WHERE GASES LIQUEFY)

FINAL ULTIMATE THERMOMETER: CARNOT ENGINE!

# INTERNAL COMBUSTION ENGINE



(a) (b) (c) (d)

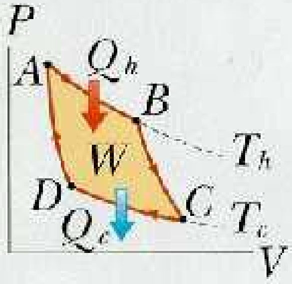


**Figure 22.9**

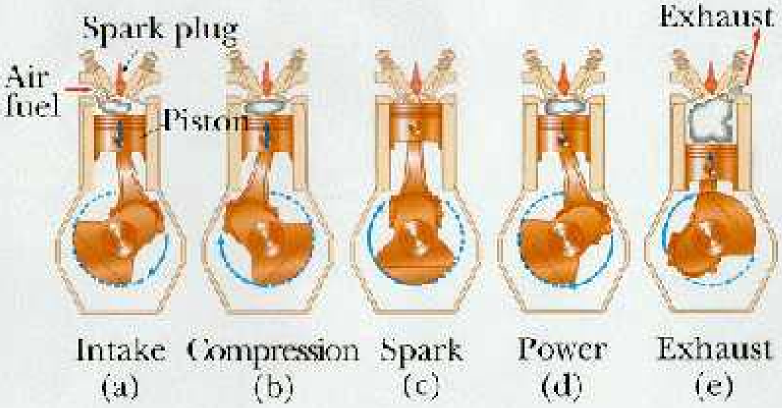
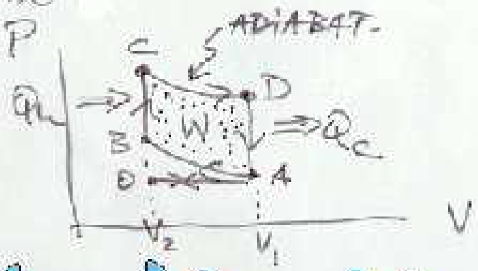


**Figure 22.10**

Overhead transparencies to accompany
Serway, *Physics for Scientists and Engineers with Modern Physics, 4/e*
Transparency Number 75, Figures 22.9 and 22.10

# GASOLINE ENGINE

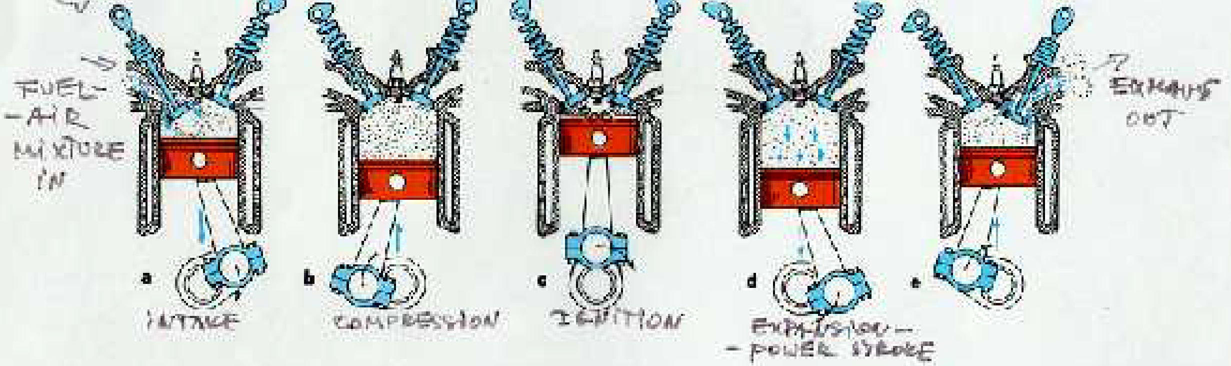
OTTO CYCLE:



$\frac{V_1}{V_2}$ COMPRESS. RATIO

$$e = 1 - \frac{1}{(V_1/V_2)^{\gamma - 1}}$$

$$\gamma = \frac{c_p}{c_v}$$



A FOUR-CYCLE INTERNAL COMBUSTION ENGINE

FOR $\frac{V_1}{V_2} \simeq 8$ & $\gamma_{AIR} = 1.4$, $e_{THEOR} = 56\%$

DIESEL: $\frac{V_1}{V_2} \simeq 16$

$e_{REAL} \simeq 15$ TO $20\%$

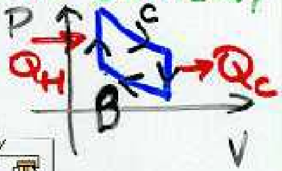
(FRICTION, INCOMPLETE COMBUSTION, HEAT LOSS)

**Figure 17.5**
*Conceptual Physics*, Seventh Edition, by Paul G. Hewitt

WHY IS THERE II LAW: $e<1$, EVEN IF WE ELIMINATED FRICTION?

REASON: WE NEED A CYCLIC, REPETITIVE PROCESS OF CONVERSION $Q \to W$.

IN (C) GAS/AIR MIXTURE EXPLODES, DRIVING THE PISTON DOWN. THIS COULD BE 100% EFFICIENT, E.G. VIA ISOTHERM PROCESS.



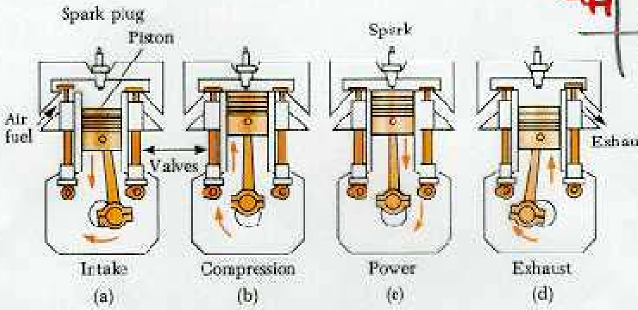


Fig. 13-8

BUT THE PISTON HAS TO BE RETURNED TO THE TOP IN (B) TO PREPARE FOR THE NEXT CYCLE, TO KEEP CAR GOING. YOU HAVE TO COOL THE CYLINDER, OTHERWISE IN COMPRESSION (B) YOU WOULD FINISH THE CYCLE AT A HIGHER TEMPERATURE THAT IT HAD AT THE BEGINNING.

$e<1$ THIS HEAT IS CARRIED AWAY BY

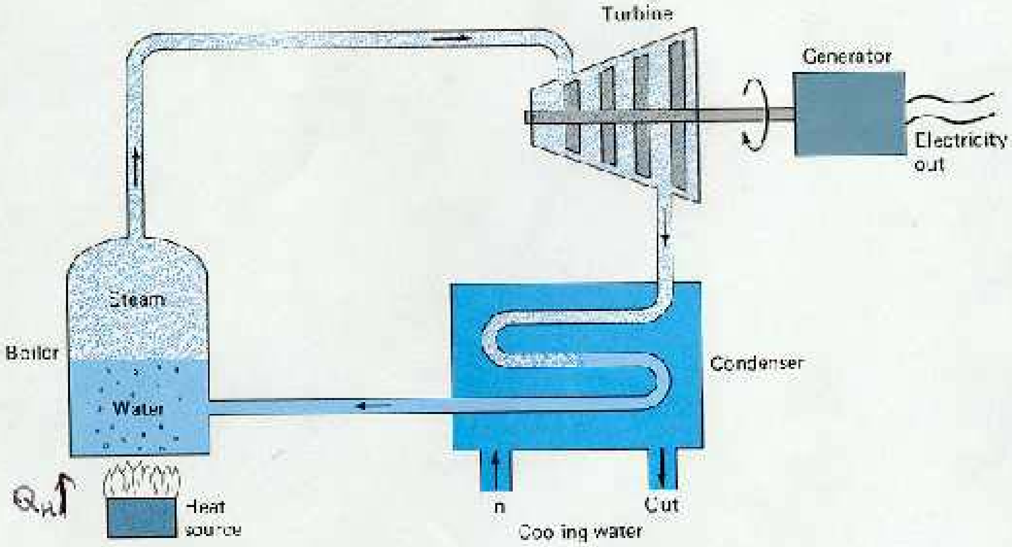
22) THE COOLING SYSTEM/RADIATOR.

24)

**Transparency 14 (Fig. 19–16)**

*Physics: Extended with Modern Physics* by Wolfson and Pasachoff.

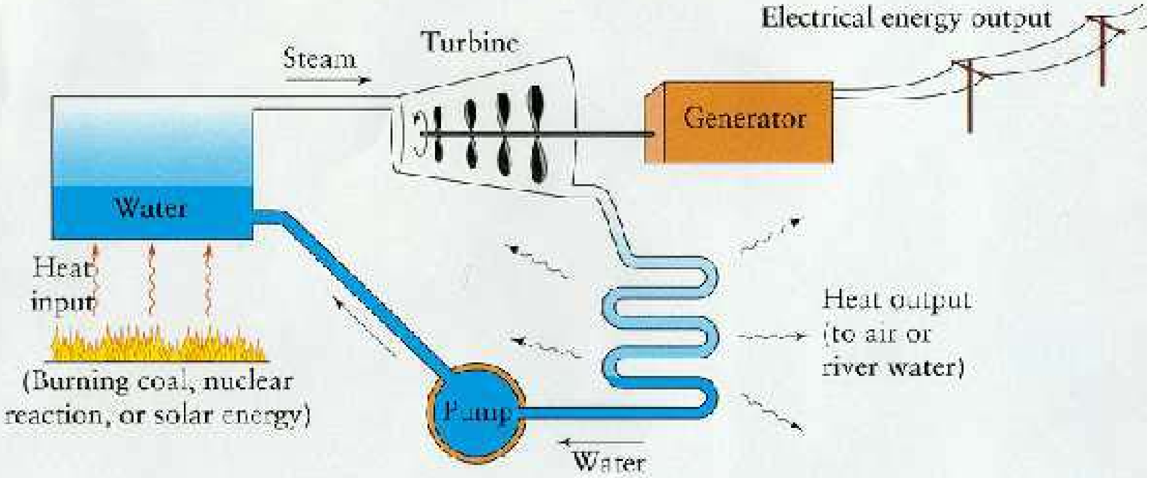
THERMAL POWER PLANT: HEAT TO ELECTRICITY



$Q_H \uparrow$

FUEL: COAL
GAS
OIL
NUCLEAR

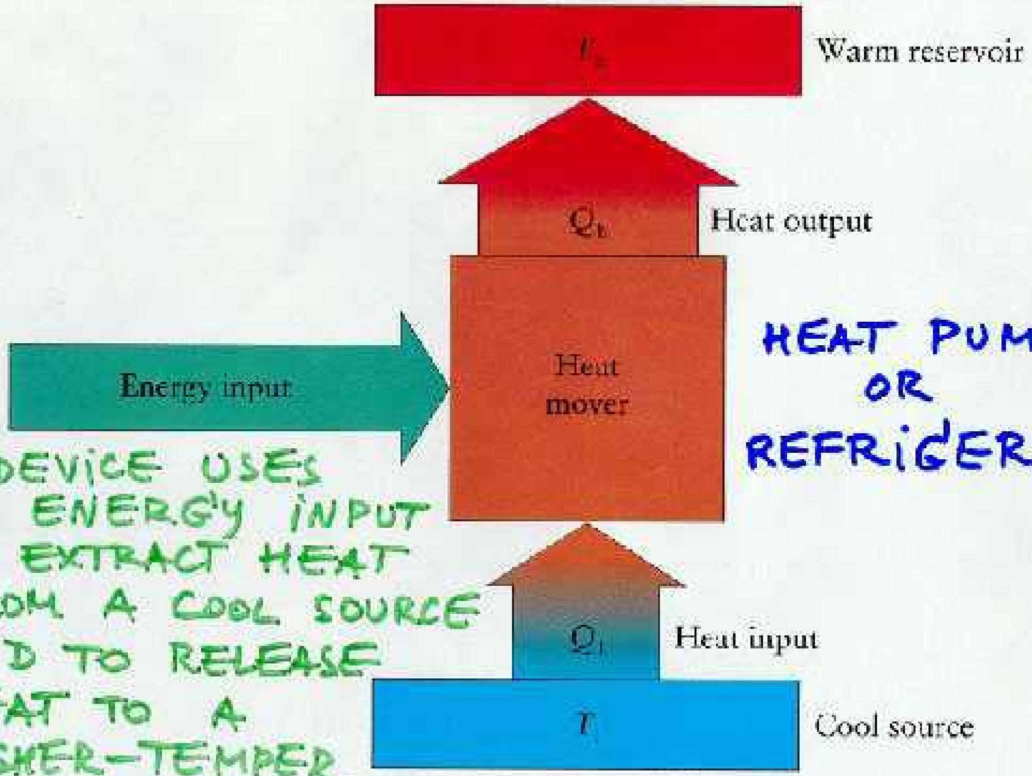
## Sketch of a Steam–Electric Power Plant



Acetate 68 (Figure 5.37)

3/) + 26,27,28,29,30

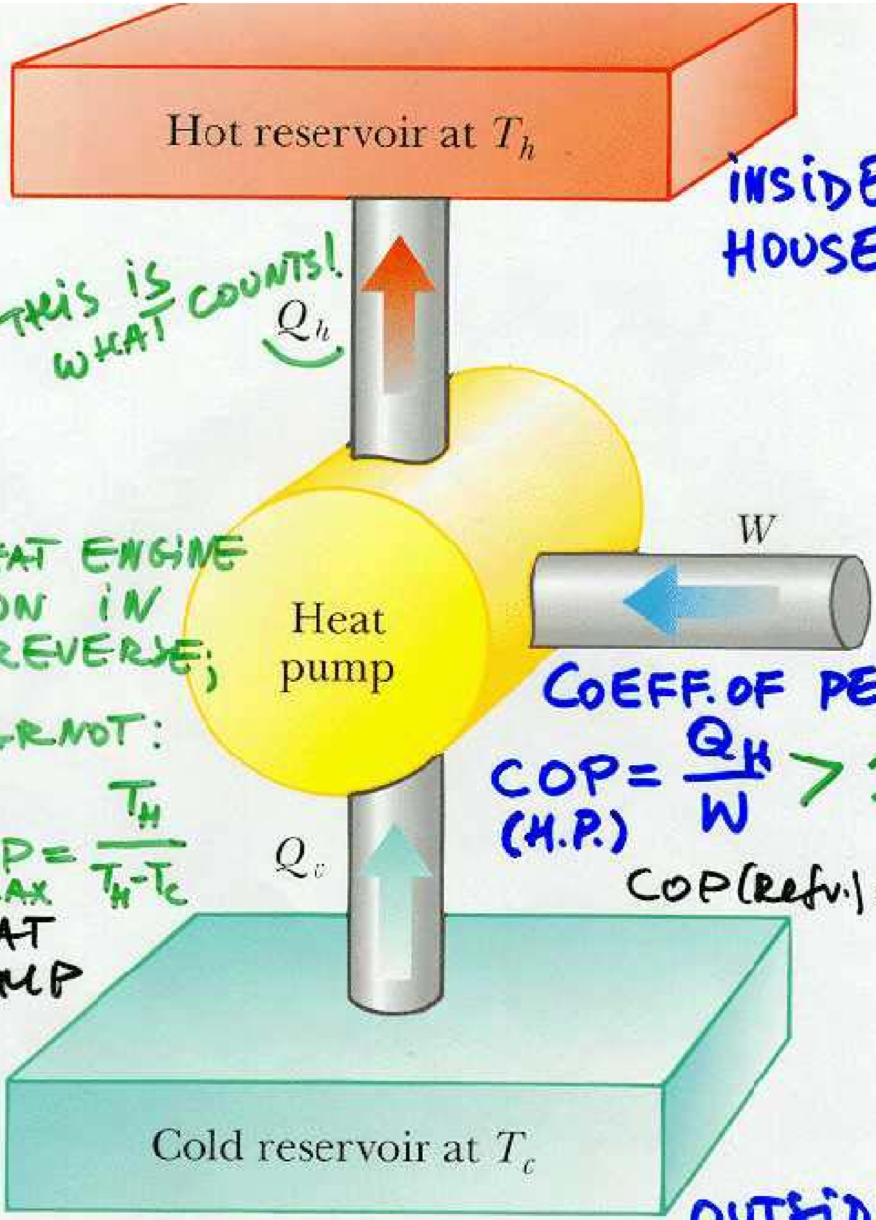
## Diagram of a Heat Mover



HEAT PUMP
OR
REFRIGERATOR

A DEVICE USES AN ENERGY INPUT TO EXTRACT HEAT FROM A COOL SOURCE AND TO RELEASE HEAT TO A HIGHER-TEMPER RESERVOIR.

Acetate 71 (Figure 8.1)



INSIDE HOUSE

THIS IS WHAT COUNTS!

HEAT ENGINE RUN IN REVERSE;

CARNOT:

$$COP_{MAX} = \frac{T_H}{T_H - T_C}$$

HEAT PUMP

COEFF. OF PERF.

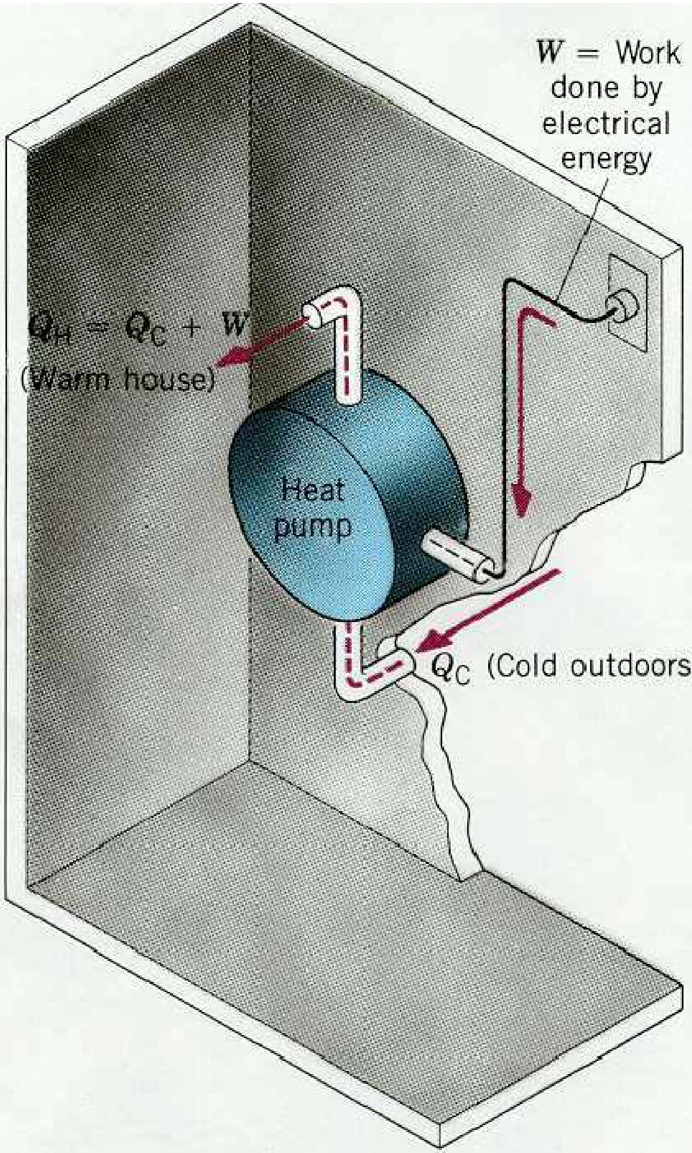
$$\underset{(H.P.)}{COP} = \frac{Q_H}{W} > 1$$

$$COP(\text{Refr.}) = \frac{Q_c}{W}$$

OUTSIDE HOUSE

Overhead transparencies to accompany Serway/Faughn: *College Physics, 4/e*
Figure 62 Text figure 12.12 page 368
Schematic diagram of a heat pump

32)



33)

FIGURE 15.18

34)

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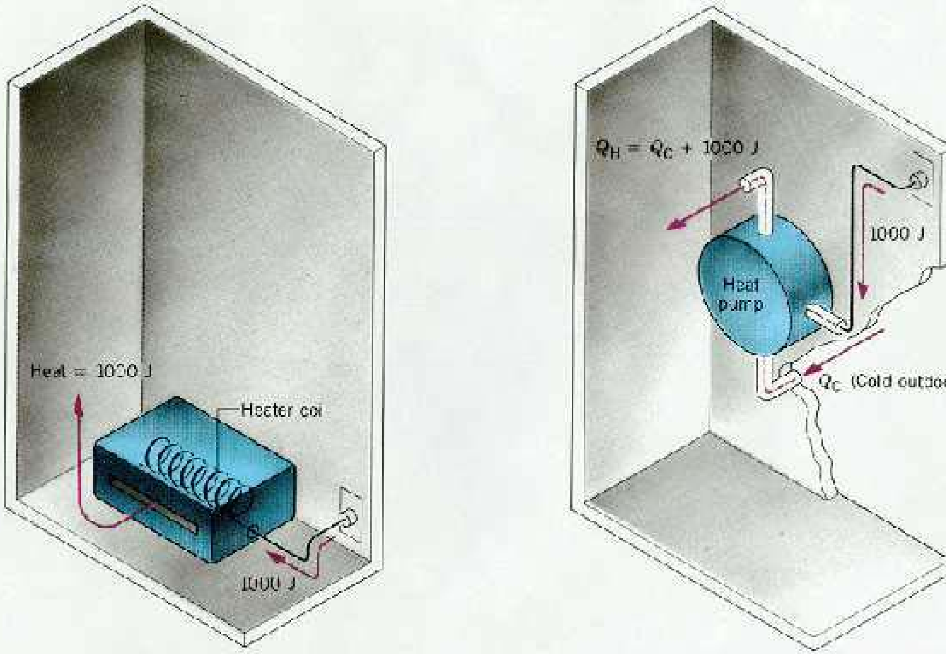
FIGURE 15.19

137



(a) Conventional electric heating

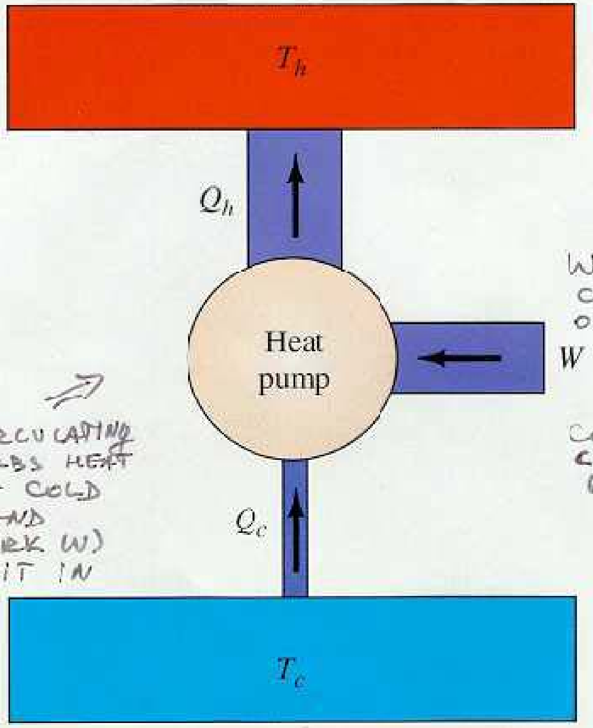
(b) Heat pump

## T75 (Figure 20-15) Schematic diagram of a heat pump

COEFF. OF PERFORM.

$\text{COP}(\text{heat pump}) = \frac{Q_h}{W} \simeq 4 \Rightarrow Q_h \simeq 4W$ (regular heater: $Q = W$!)

$T_c \gtrsim 25°F$



INSIDE AIR

W DONE BY COMPRESSOR ON THE VAPOR

HEATING: CIRCULATING FLUID ABSORBS HEAT FROM THE COLD OUTSIDE AND (USING WORK W) RELEASES IT IN THE HOUSE

COOLING: CYCLE IS REVERSED

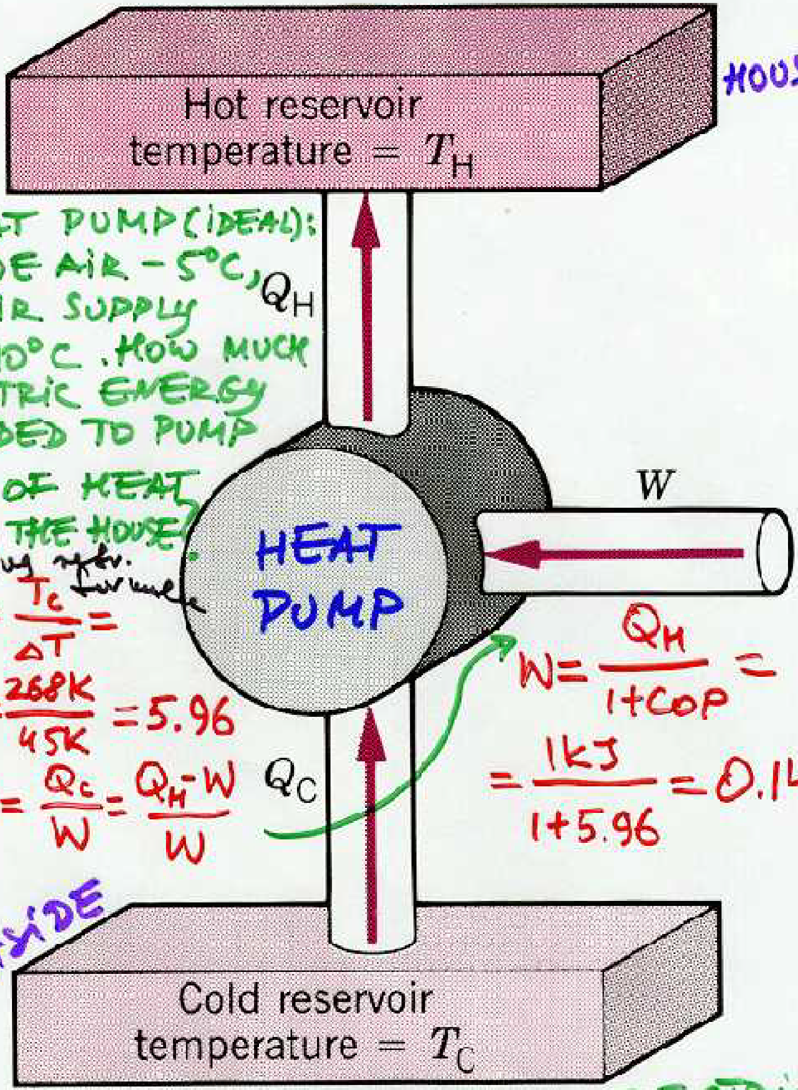
OUTSIDE AIR

A REVERSIBLE DEVICE OPERATING BOTH AS A HEATER AND A REFRIGERATOR

PHYSICS FOR SCIENTISTS
AND ENGINEERS
by Fishbane/Gasiorowicz/Thornton

A Division of Simon & Schuster
Englewood Cliffs, New Jersey 07632

# EXAMPLE:



HEAT PUMP (IDEAL): OUTSIDE AIR −5°C, HOT AIR SUPPLY AT 40°C. HOW MUCH ELECTRIC ENERGY NEEDED TO PUMP 1 kJ OF HEAT INTO THE HOUSE?

using refr. formula

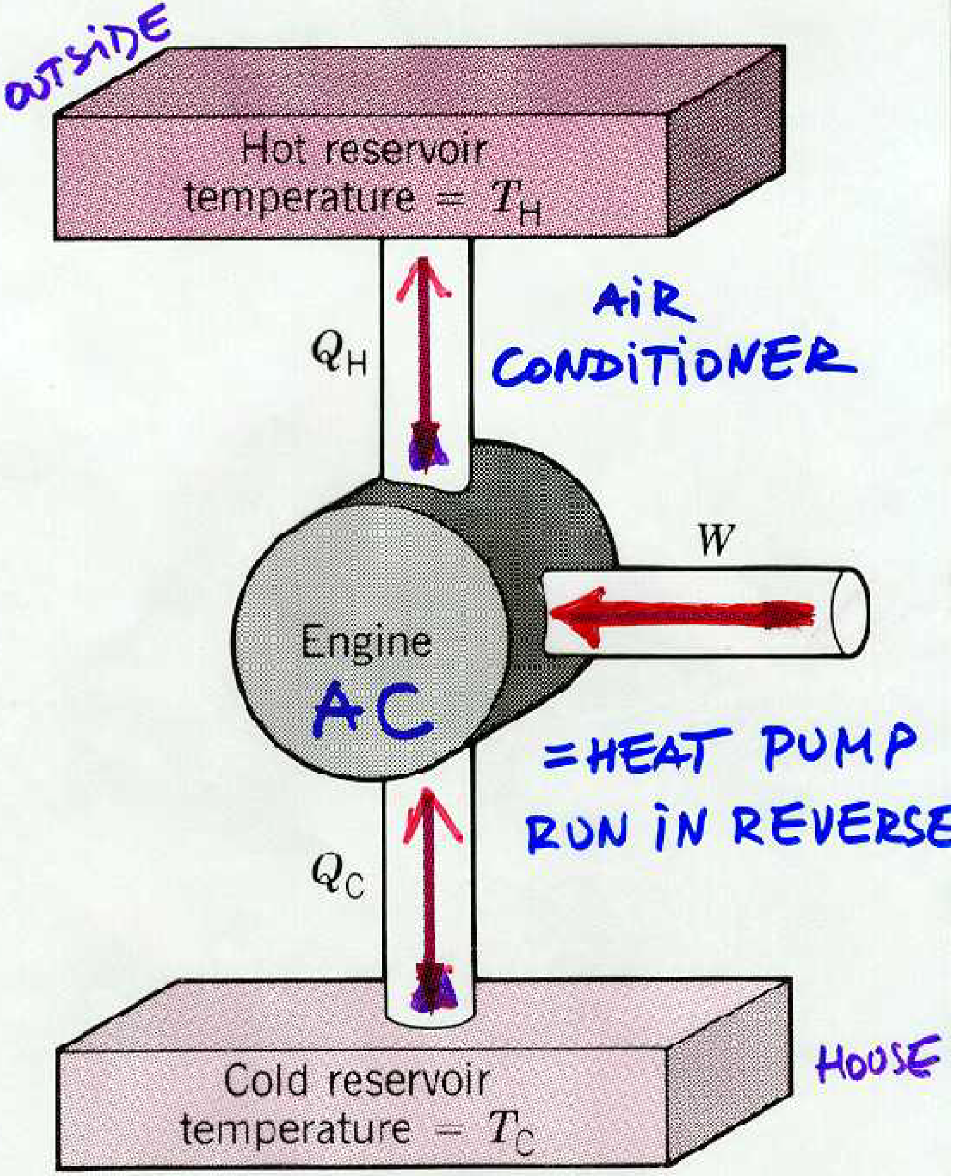
$$COP_{MAX} = \frac{T_c}{\Delta T} = \frac{268K}{45K} = 5.96$$

$$COP = \frac{Q_c}{W} = \frac{Q_H - W}{W}$$

$$W = \frac{Q_H}{1 + COP} = \frac{1kJ}{1 + 5.96} = 0.144kJ$$

ONLY 0.144 kJ NEEDED OF ELECTRIC ENERGY TO PUMP 1 kJ OF HEAT!

FIGURE 15.15



OUTSIDE

AIR CONDITIONER

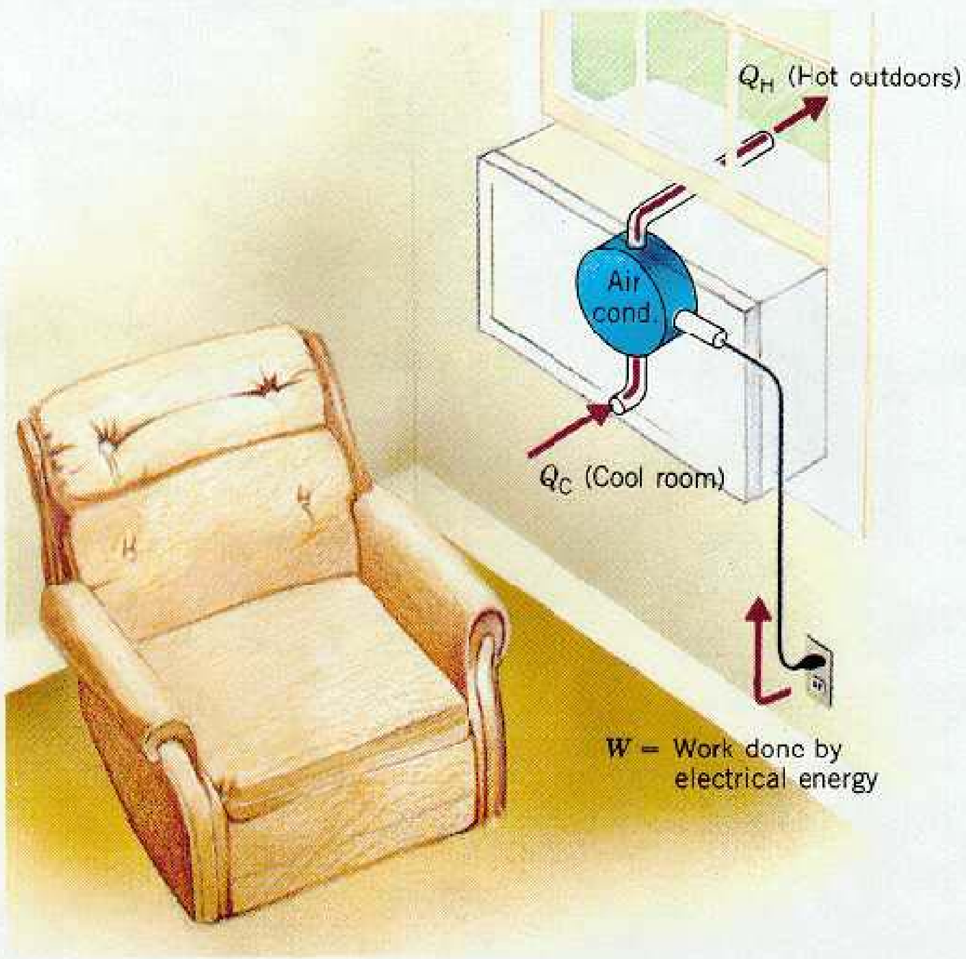
AC

=HEAT PUMP RUN IN REVERSE

HOUSE

FIGURE 15.14

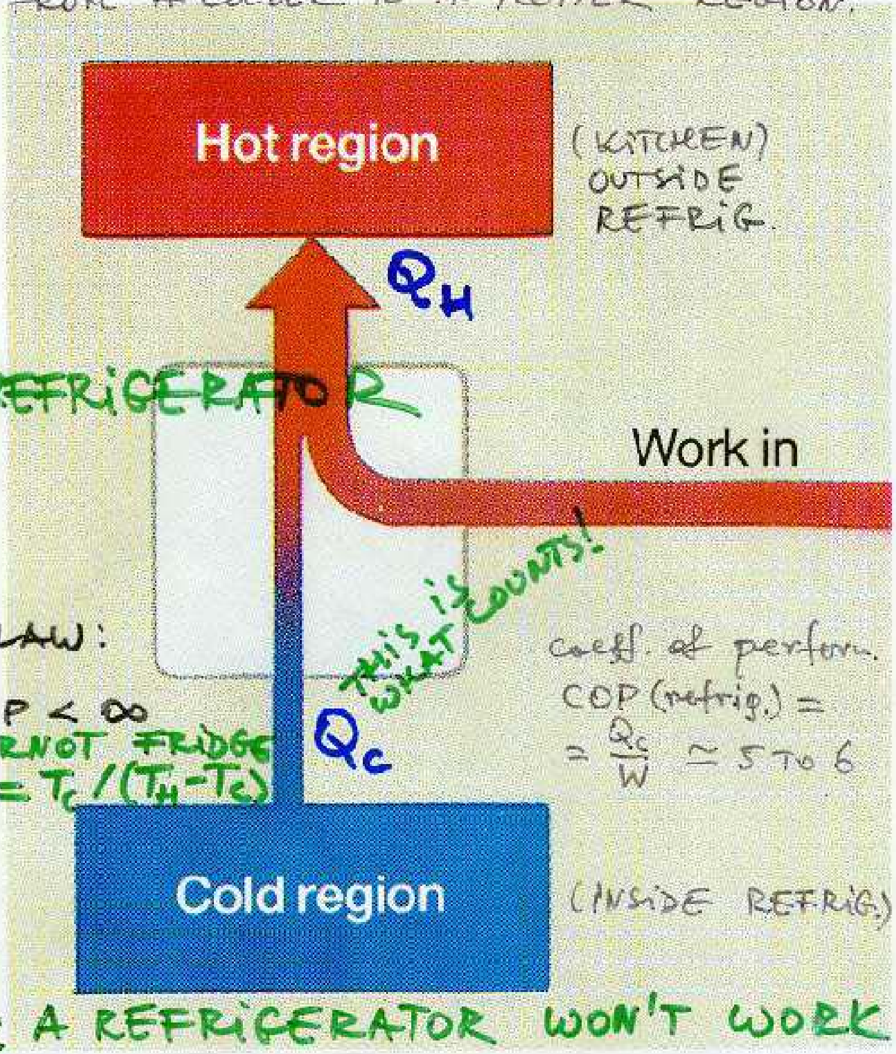
37)



3e)

FIGURE 15.17

REFRIGERATOR USES MECHANICAL WORK TO TRANSFER THERMAL ENERGY FROM A COLDER TO A HOTTER REGION.



(KITCHEN) OUTSIDE REFRIG.

(INSIDE REFRIG.)

II LAW:

COP < ∞

CARNOT FRIDGE

$COP = T_C / (T_H - T_C)$ MAX

coeff. of perform.

COP (refrig.) =

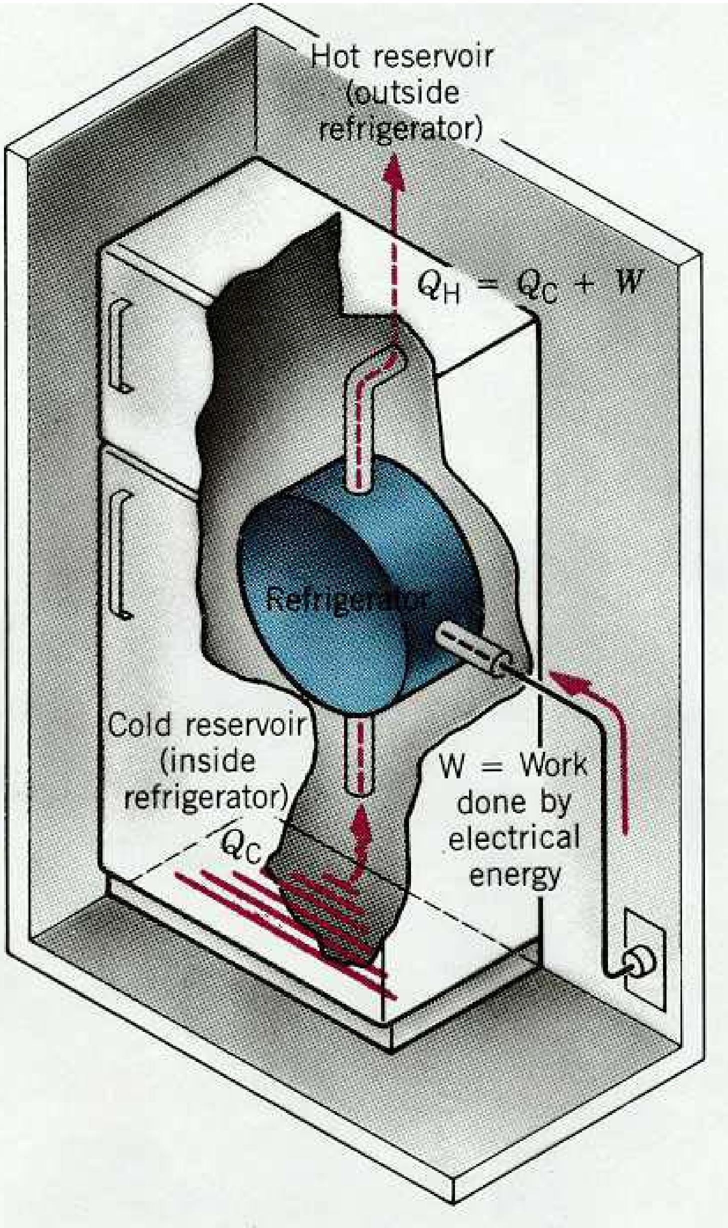
$= \frac{Q_C}{W} \simeq 5 \text{ to } 6$

II LAW: A REFRIGERATOR WON'T WORK

39)

29. **Figure 10.12**, Kirkpatrick/Wheeler

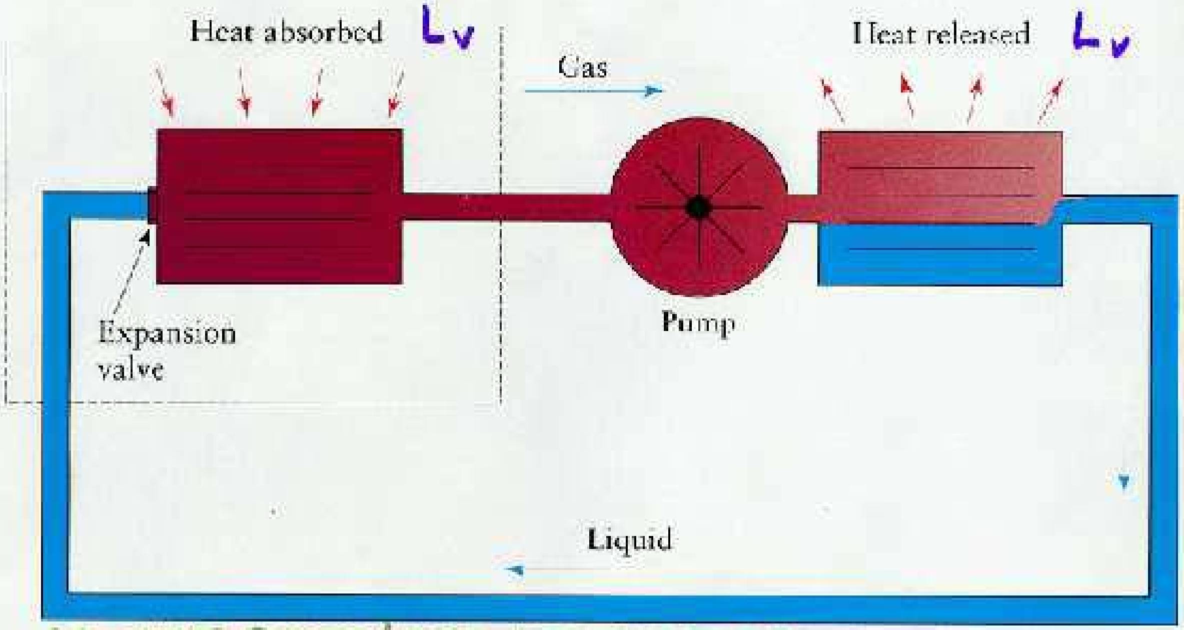
UNLESS IT'S PLUGGED IN!



40)

FIGURE 15.16

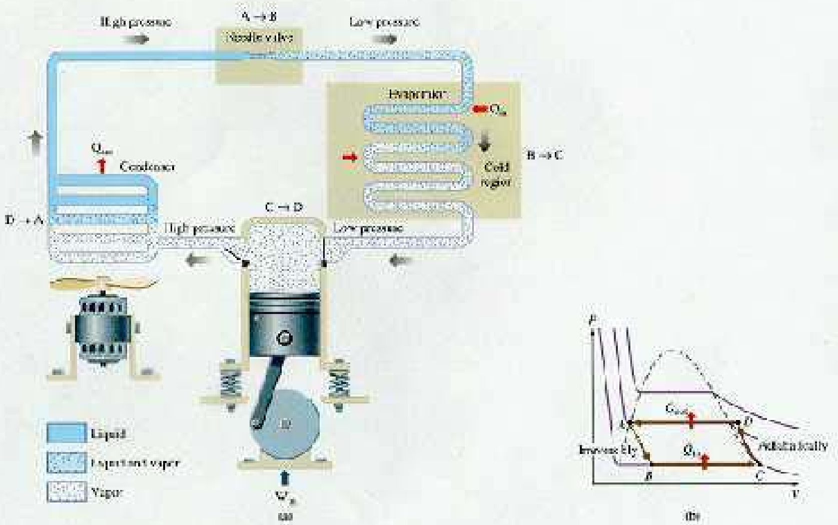
# Refrigerator Cooling Cycle

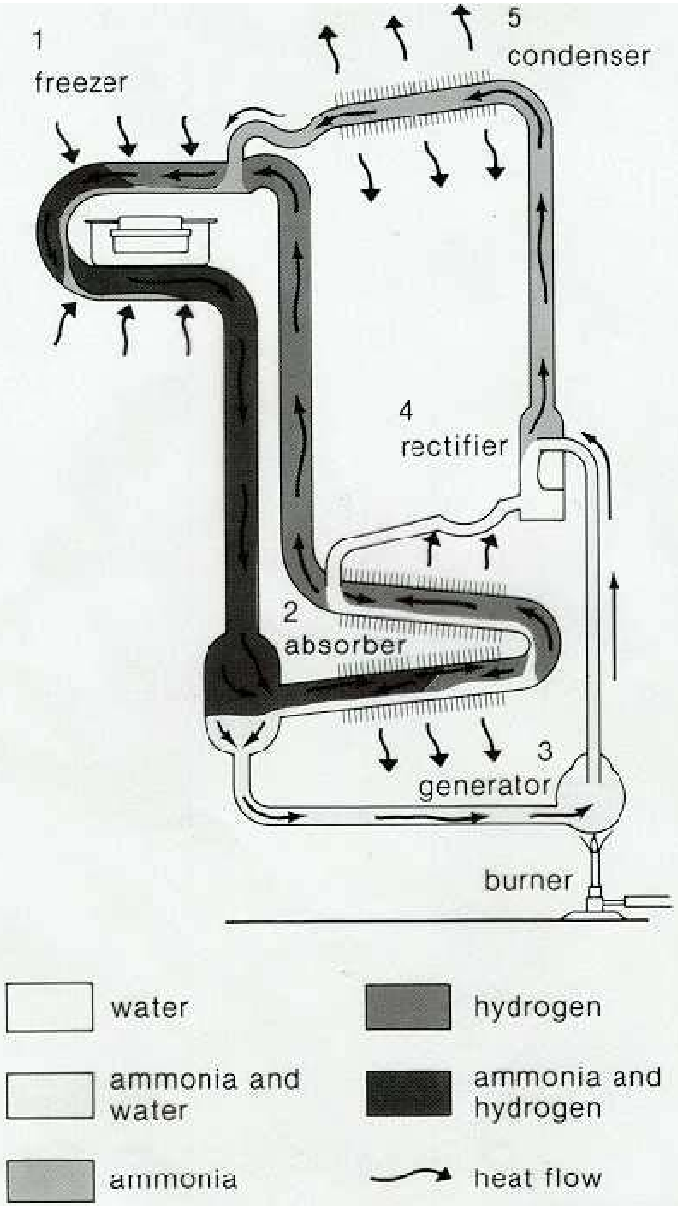


AS THE REFRIGERANT VAPORIZES, IT ABSORBS HEAT $L_V$ FROM THE REFRIGERATOR'S INTERIOR; AS IT CONDENSES, IT RELEASES HEAT TO THE ROOM.

Acetate [illegible] (Figure [illegible])

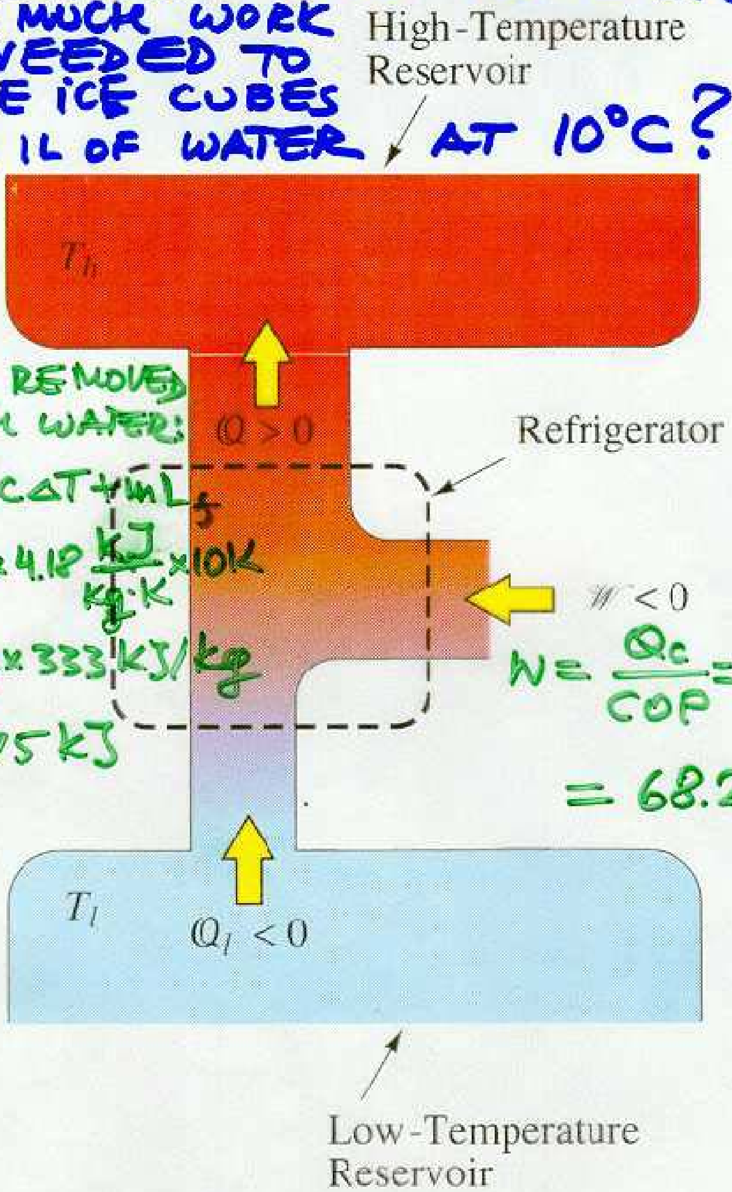
# A Refrigeration System




1
freezer
5
condenser
4
rectifier
2
absorber
3
generator
burner
water
ammonia and water
ammonia
hydrogen
ammonia and hydrogen
heat flow

42')

EXAMPLE: GIVEN COP = 5.5, HOW MUCH WORK IS NEEDED TO MAKE ICE CUBES FROM 1L OF WATER AT 10°C?



HEAT REMOVED FROM WATER:

$$|Q_c| = mc\Delta T + mL_f$$

$$= 1\,kg \times 4.18 \frac{kJ}{kg \cdot K} \times 10K$$

$$+ 1\,kg \times 333\,kJ/kg$$

$$= 375\,kJ$$

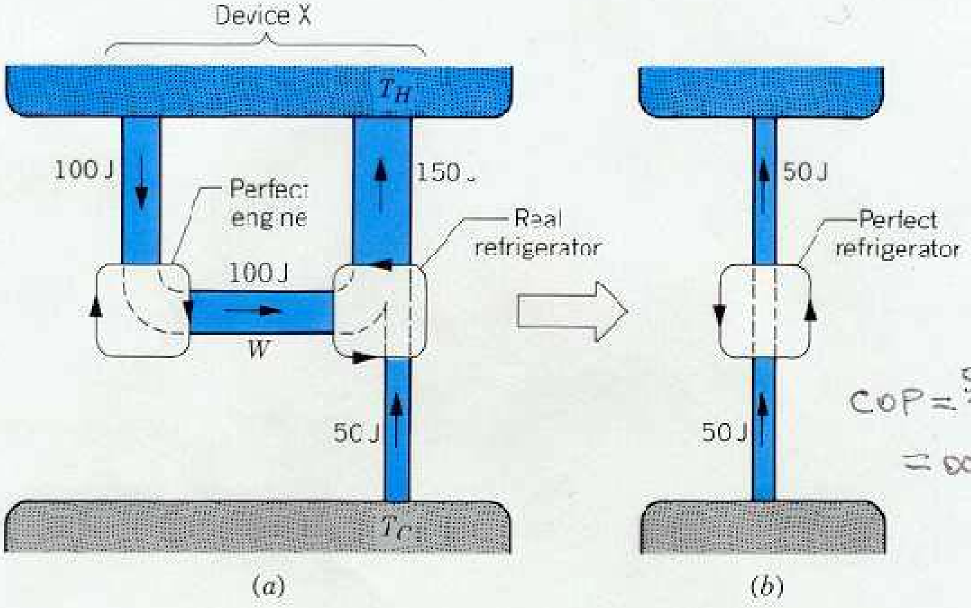
$$W = \frac{Q_c}{COP} = \frac{375\,kJ}{5.5}$$

$$= 68.2\,kJ$$

**68** The Carnot Refrigerator Diagram
Figure 20.5

Crummett, William P. and Western, Arthur B. *University Physics: Models and Applications*

A "PERFECT" REFRIGERATOR CONSTRUCTED FROM A "PERFECT" ENGINE AND A "REAL" REFRIGERATOR



(a) (b)

$COP = \frac{50J}{0}$

$= \infty!$

CONCLUSION: PERFECT REFRIGERATOR IS IMPOSSIBLE, BECASE PERFECT ENGINE IS IMPOSSIBLE.

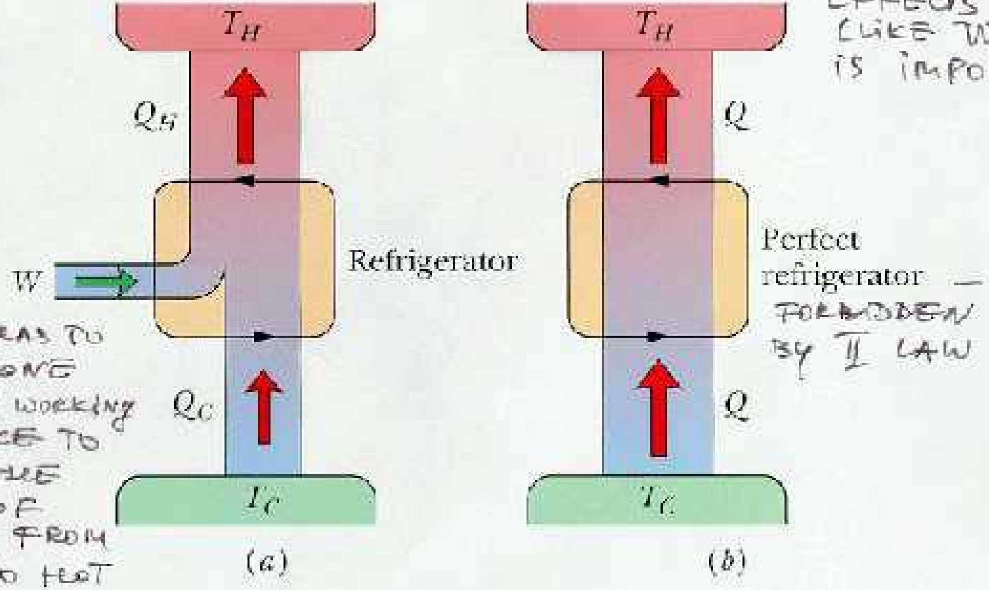
A "perfect" refrigerator constructed from a "perfect" engine and a "real" refrigerator.

FIG. 22.5

44)

45

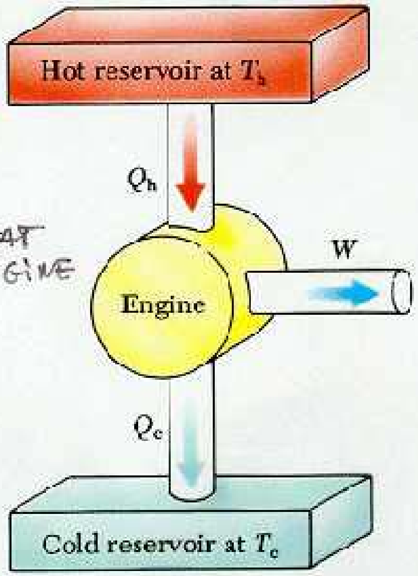
ALTERNATIVE FORMULATION OF THE II LAW:
THE CYCLIC MACHINE TRANSFERRING HEAT FROM COLD TO HOT WITHOUT ANY OTHER EFFECTS (LIKE W) = IS IMPOSSIBLE



— FORBIDDEN BY II LAW

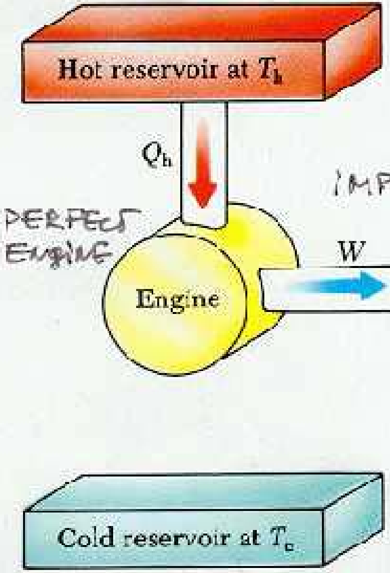
WORK HAS TO BE DONE ON THE WORKING SUBSTANCE TO FORCE THE FLOW OF HEAT FROM COLD TO HOT

FIGURE 22-6



HEAT ENGINE

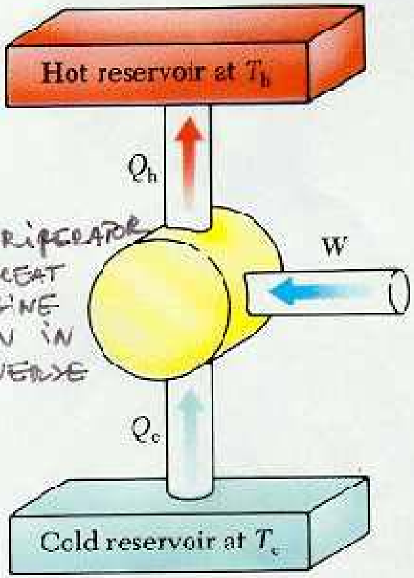
Heat engine



PERFECT ENGINE

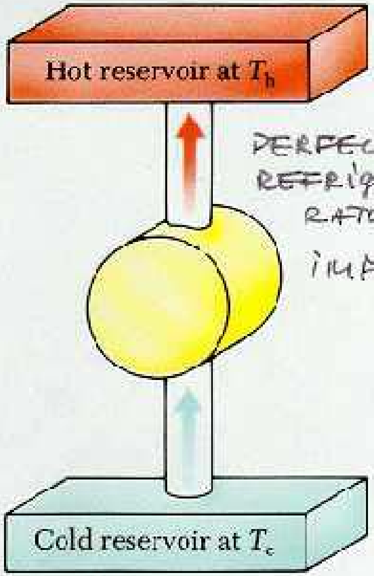
¡IMPOSSIBLE!

The impossible engine



REFRIGERATOR IS HEAT ENGINE RUN IN REVERSE

Refrigerator



PERFECT REFRIGERATOR – ¡IMPOSSIBLE

Impossible refrigerator

63. Serway Fig. 22.1, Fig. 22.3, Fig. 22.4, Fig. 22.5

# ENTROPY

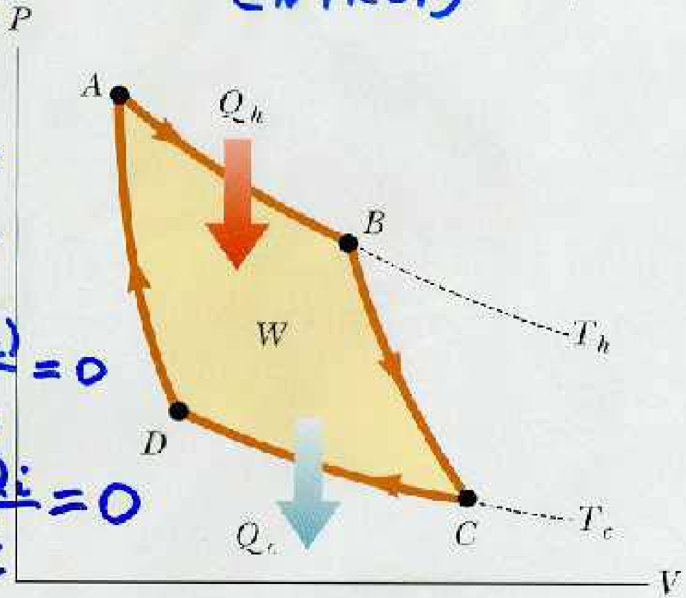
CARNOT CYCLE:

$$\frac{Q_c}{T_c} = \frac{Q_h}{T_h}$$

OR

$$\frac{Q_h}{T_h} + \frac{(-Q_c)}{T_c} = 0$$

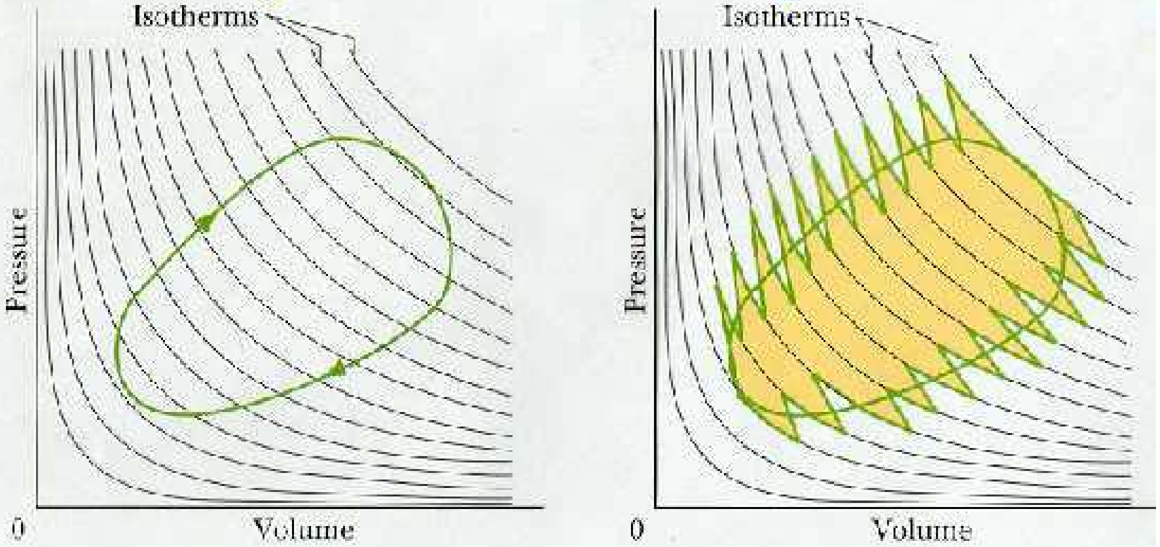
$$\sum_i \frac{\Delta Q_i}{T_i} = 0$$



Overhead transparencies to accompany Serway/Faughn: *College Physics, 4/e*
Figure 61 Text figure 12.11 page 366
The *P-V* diagram for the Carnot cycle

ANY REVERSIBLE CYCLE:

$$\sum_i \frac{\Delta Q_i}{T_i} = 0 \Rightarrow \oint \frac{dQ}{T} = 0$$



(a) (b)

FIGURE 22-11

A CYCLIC REVERSIBLE PROCESS AS A SERIES OF CARNOT CYCLES.

ANALOG: $\oint \vec{F}\cdot d\vec{s}=0 \Rightarrow$ exists POTENT. ENERGY: $\Delta U = -\int_A^B \vec{F}\cdot d\vec{s}$

HERE: STATE FUNCTION $S \equiv$ ENTROPY,

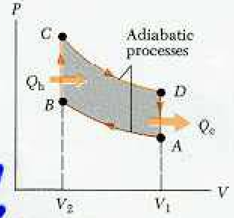


Fig. 13-9

$$\Delta S = \int_A^B \frac{dQ}{T} \quad , \Delta S = S_B - S_A$$

FOR A REVERSIBLE PATH

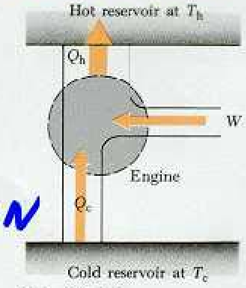
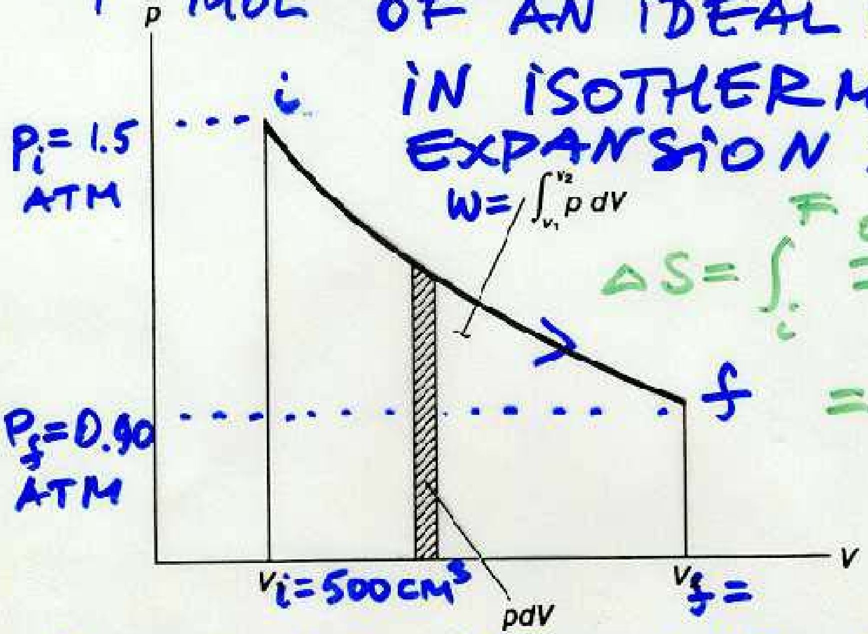


Fig. 13-11

ENTROPY DEPENDS ONLY ON A POSITION ON THE P-V DIAGRAM, SO $\Delta S$ is PATH-INDEPENDENT.

EXAMPLE: CALCULATE THE ENTROPY CHANGE OF 1 MOL OF AN IDEAL GAS IN ISOTHERMAL EXPANSION:



$$\Delta S = \int_i^f \frac{dQ}{T} = \frac{Q}{T}$$

I LAW: $dQ = d\overline{W} + d\underbrace{U}_{0!} = d\overline{W}$

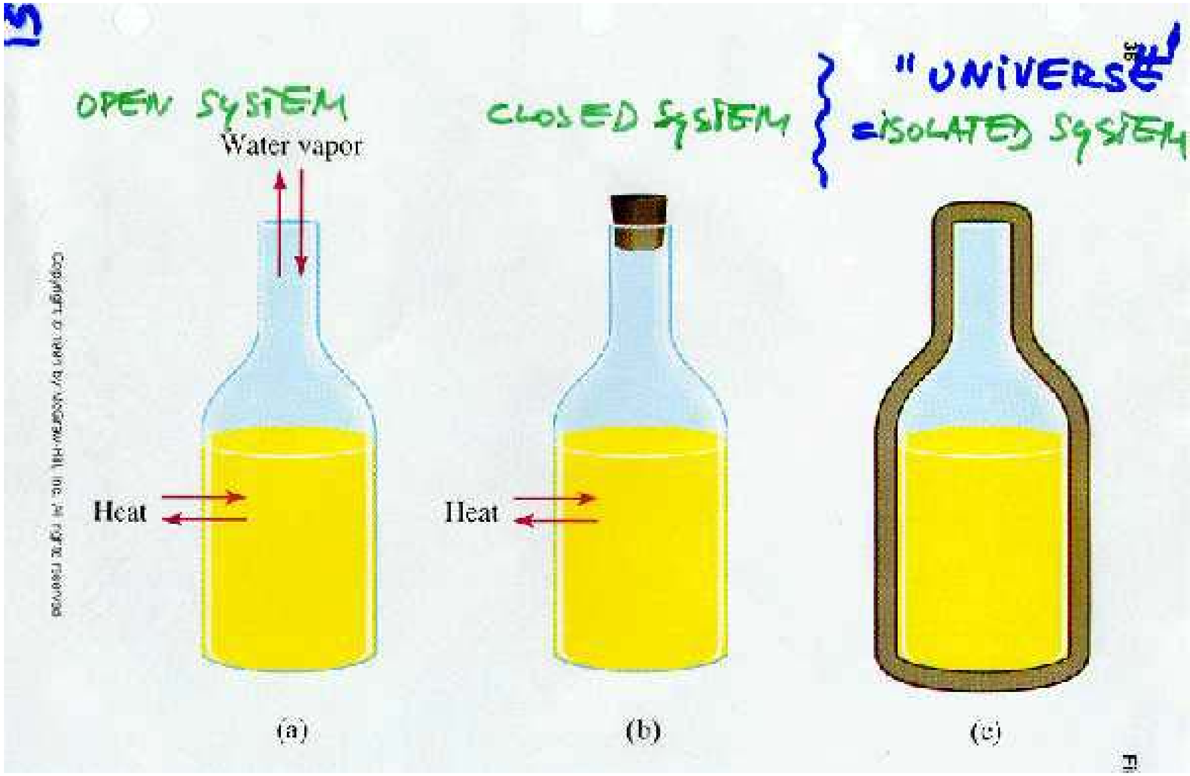
Figure 19-12

$$Q = W = \int p\,dV = nRT \int \frac{dV}{V} = nRT \ln \frac{V_f}{V_i}$$

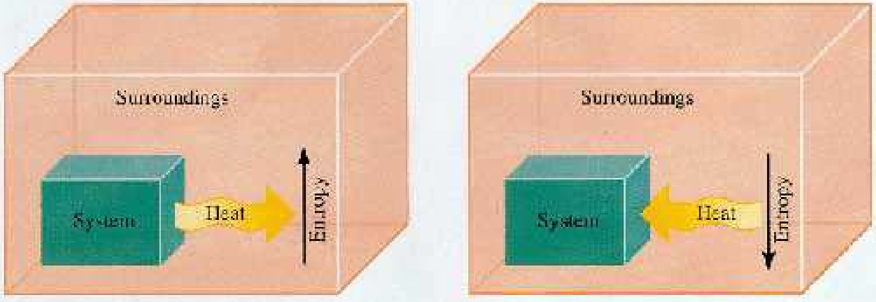
$$\Delta S = \frac{Q}{T} = -nR \ln \frac{P_f}{P_i} = -(1\ \mathrm{MOL}) \times$$

$$\times\ 8.3 \frac{\mathrm{J}}{\mathrm{MOL \cdot K}} \times \ln(0.90/1.50) = 4.2 \frac{\mathrm{J}}{\mathrm{K}}$$

$$\Delta S = 4.2\ \mathrm{J/K}$$


15
OPEN SYSTEM
Water vapor
Heat
CLOSED SYSTEM
Heat
"UNIVERSE"
= ISOLATED SYSTEM
(a)
(b)
(c)

ENTROPY OF "UNIVERSE" =
= ENTROPY OF SURROUNDINGS AND SYSTEM



(a) (b)

Figure

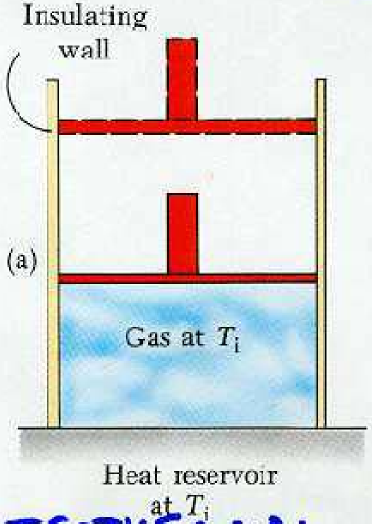
FOR A REVERSIBLE PROCESS

$T_{sys} = T_{SORR}$, AND $\Delta S_{sys} = \frac{-Q}{T}$,

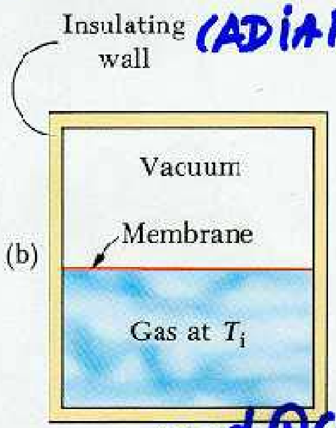
$\Delta S_{SURR} = + Q/T$

$\Delta S$ (ISOLATED SYSTEM) = 0 for REVER-SIBLE PROCESS

# FREE EXPANSION OF AN IDEAL GAS - IRREVERSIBLE



ISOTHERMAL

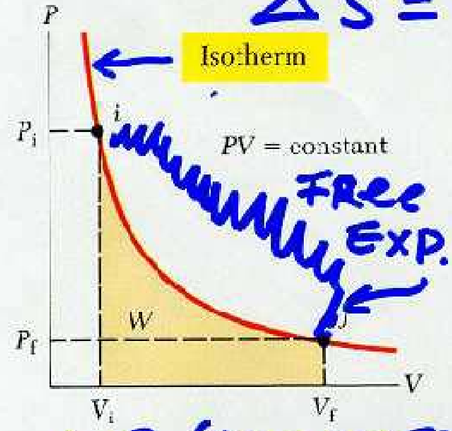


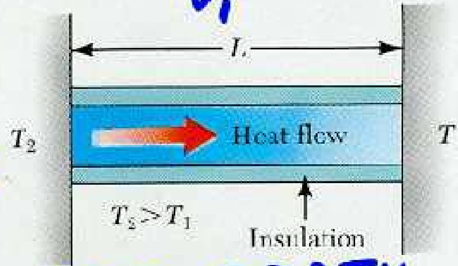
(ADIABAT.)

$$\Delta S = \int \frac{dQ(\text{rev.})}{T}$$

SAME i, f STATES - SAME

$$\Delta S = nR \ln \frac{V_2}{V_1} > 0$$





FOR IRREV. PROCESS:

$$\Delta S \text{ (ISOLATED SYSTEM)} > 0$$

Serway Fig. 20.6, Fig. 20.7, Fig. 20.9

IN GENERAL:

REVERSIBLE PROCESS:

$\Delta S$ (UNIVERSE) $= 0$

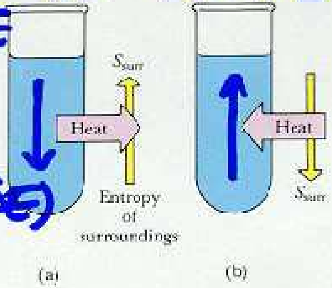


FIGURE 16.12

IRREVERS. PROCESS:

$\Delta S$ (universe) $> 0$

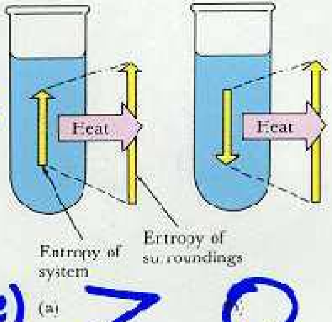


FIGURE 16.14

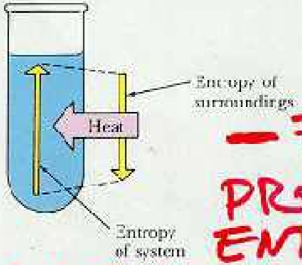


FIGURE 16.15

II LAW:

$\Delta S \geq 0$

– FOR ANY PROCESS, ENTROPY OF THE UNIVERSE NEVER DECREASES

T-150
FIGURES 16.12, 16.14, 16.15

Atkins/Beran
GENERAL CHEMISTRY, Second Edition
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# ORDER AND DISORDER

$$= \frac{Q}{T} = \frac{mL_f}{T}$$

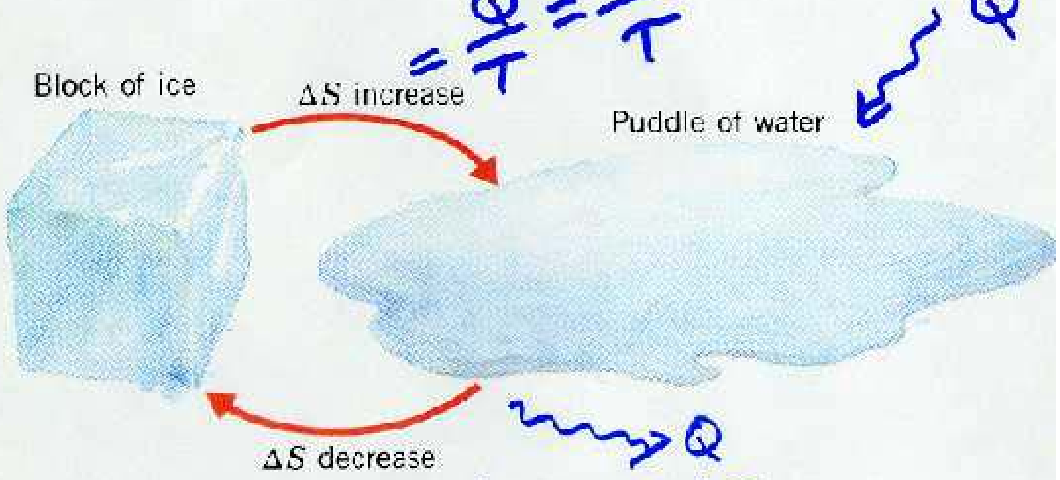


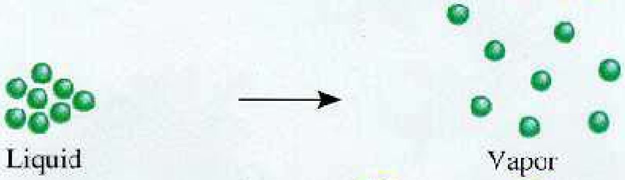
**FIGURE 15.24**

HEAT FLOW INTO THE SYSTEM INCREASES ENTROPY AND DISORDER

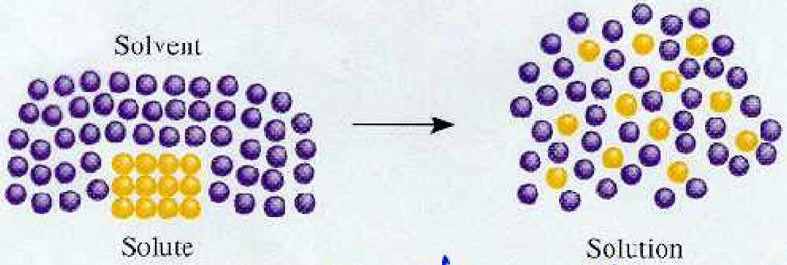
THE PROCESSES THAT LEAD TO AN INCREASE IN ENTROPY OF THE SYSTEM

Figure 19.2

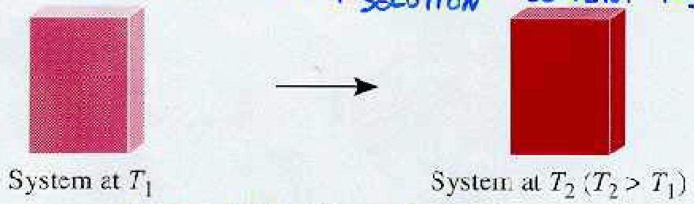
MELTING: (a) $S_{LIQUID} > S_{SOLID}$



VAPORIZATION (b) : $S_{VAPOR} > S_{LIQUID}$



DISSOLVING: (c) $S_{SOLUTION} > S_{SOLVENT} + S_{SOLUTE}$



HEATING (d) : $S(T_2) > S(T_1)$

$$\Delta S = \int \frac{dQ}{T} = mc \int \frac{dT}{T} = mc \ln(T_2/T_1)$$

ALL IRREVERSIBLE PROCESSES MOVE THE SYSTEM PLUS ITS SURROUNDINGS TOWARD A LESS ORDERED STATE:

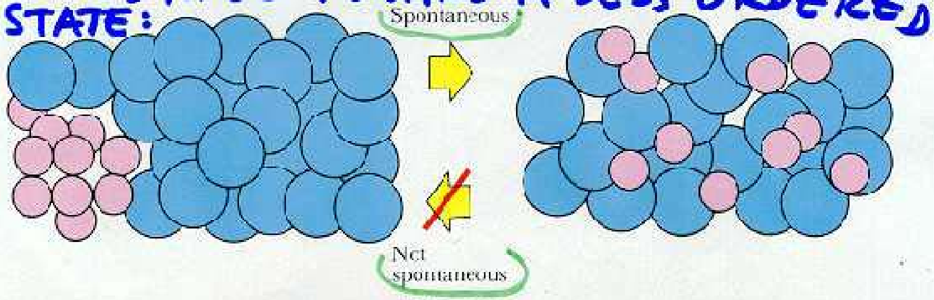
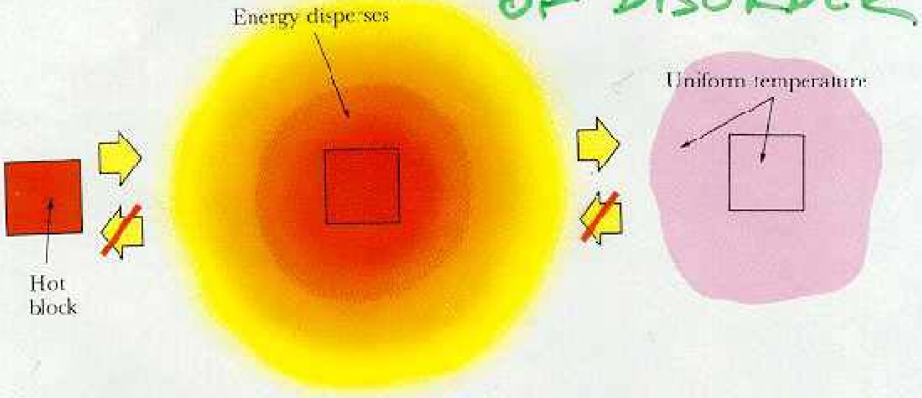


FIGURE 11.18

ENTROPY AND MIXING

ENTROPY IS A MEASURE OF DISORDER



ENTROPY AND TEMPERATURE

FIGURE 11.19

T-110
FIGURES 11.18, 11.19

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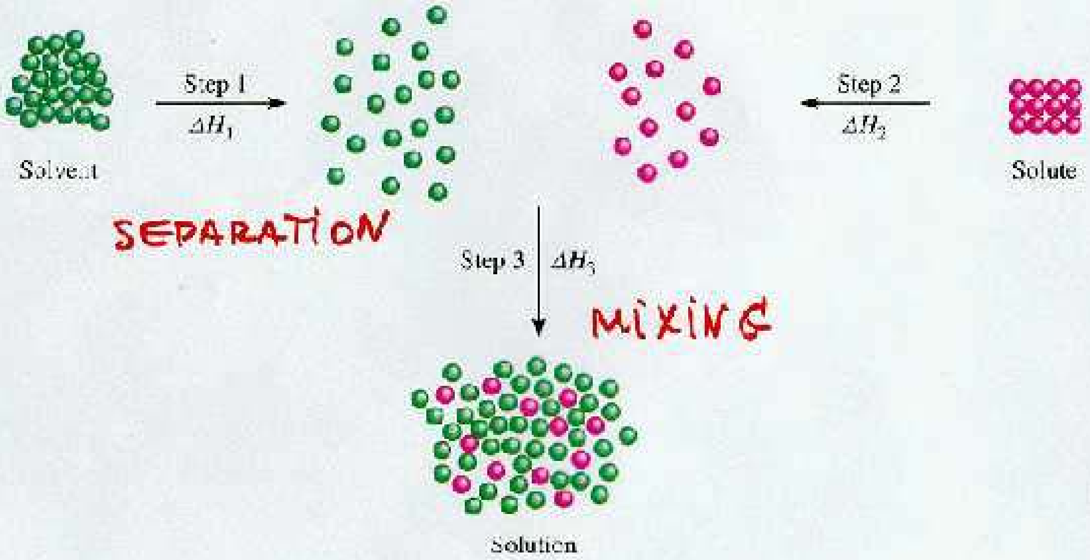
# THE SOLUTION PROCESS



$$S = k \ln W$$

$$k = \frac{R}{N_A} = 1.38 \times 10^{-23} \ J/K$$

$$S = k \ln 1$$

BOLTZMANN CONSTANT, W-PROBABILITY, OR NUMBER OF ARRANGEMENTS

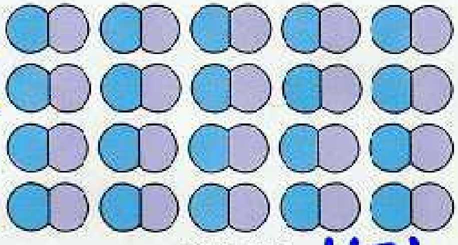


FIGURE 15.7

$W = 1$

$S = 0$

PERFECT ORDERING AT $T = 0$

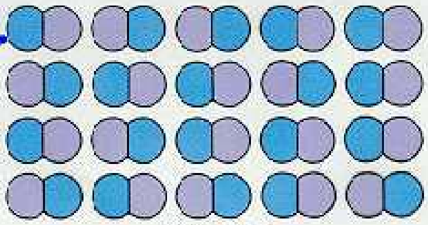


FIGURE 15.8

$S > 0$

RANDOM ORDERING AT $T = 0$

20 MOLECULES, 2 ORIENT. FOR EACH, $W = 2 \times 2 \times 2 \cdots = 2^{20}$

$$S = k \ln 2^{20} = 20 k \ln 2 = 1.9 \times 10^{-22} \ \frac{J}{K}$$

T-148

FIGURES 16.7, 16.8

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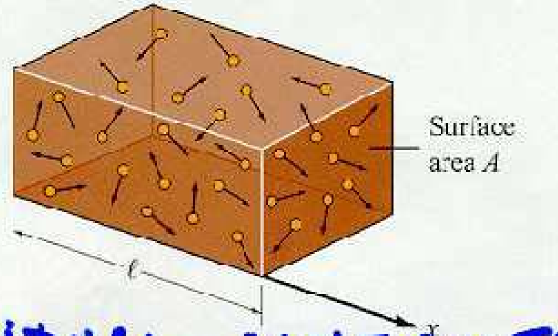
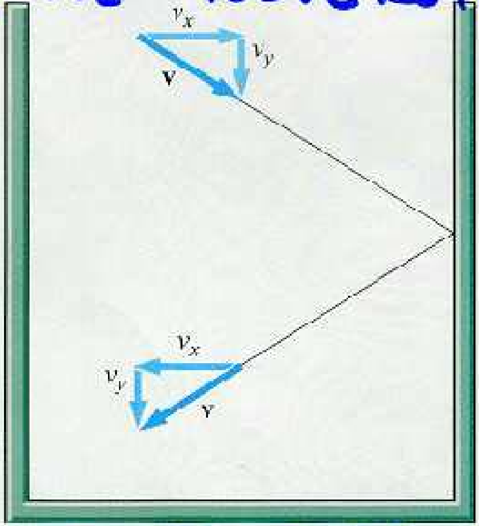
# ENTROPY AND ARROW OF TIME



INDIVIDUAL MOLECULES MOVE IN A TIME-REVERSIBLE WAY



-NO PREFERRED DIRECTION OF TIME

Figures 20-[illegible], 20-[illegible]
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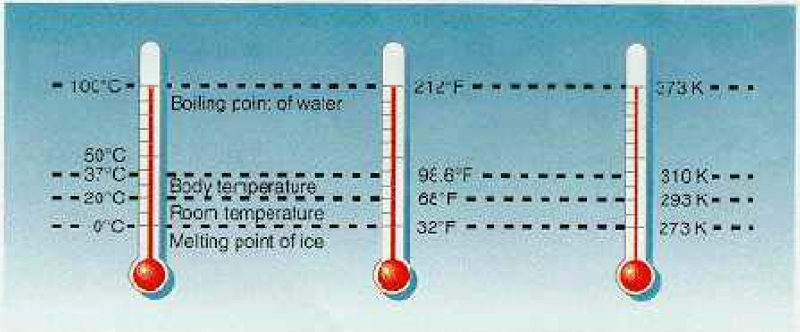
# ARROW OF TIME

MORE ORDER → MORE DISORDER

SPONTANEOUSLY!

LESS ENTROPY → MORE ENTROPY IN ISOLATED SYSTEM

REASON: STATISTICAL — COLLISIONS BETWEEN MOLECULES LEAD TO MORE DISORDERED SITUATIONS



(a) Celsius scale (b) Fahrenheit scale (c) Kelvin or absolute scale

THE ARROW OF TIME EXPRESSES SIMPLY THE OVERWHELMING LIKELIHOOD THAT LESS ORDERED SITUATIONS WILL RESULT

42 The temperature scales
Figure 14.3

Peter J. Nolan, *Fundamentals of College Physics*
© 1993, Wm. C. Brown Publishers, Dubuque, Iowa

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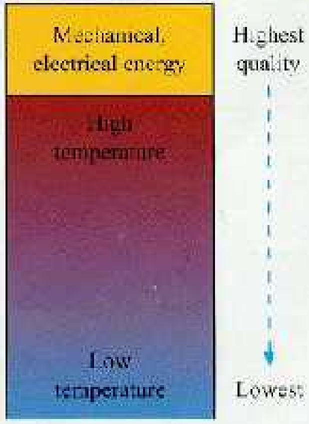
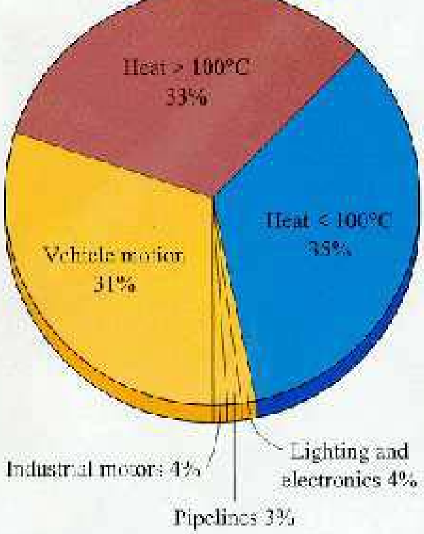
QUALITY OF ENERGY MEASURES THE VERSATILITY OF ENERGY FORMS



ENERGY USE IN THE U.S. - BY QUALITY



Figures 22-18, 22-19
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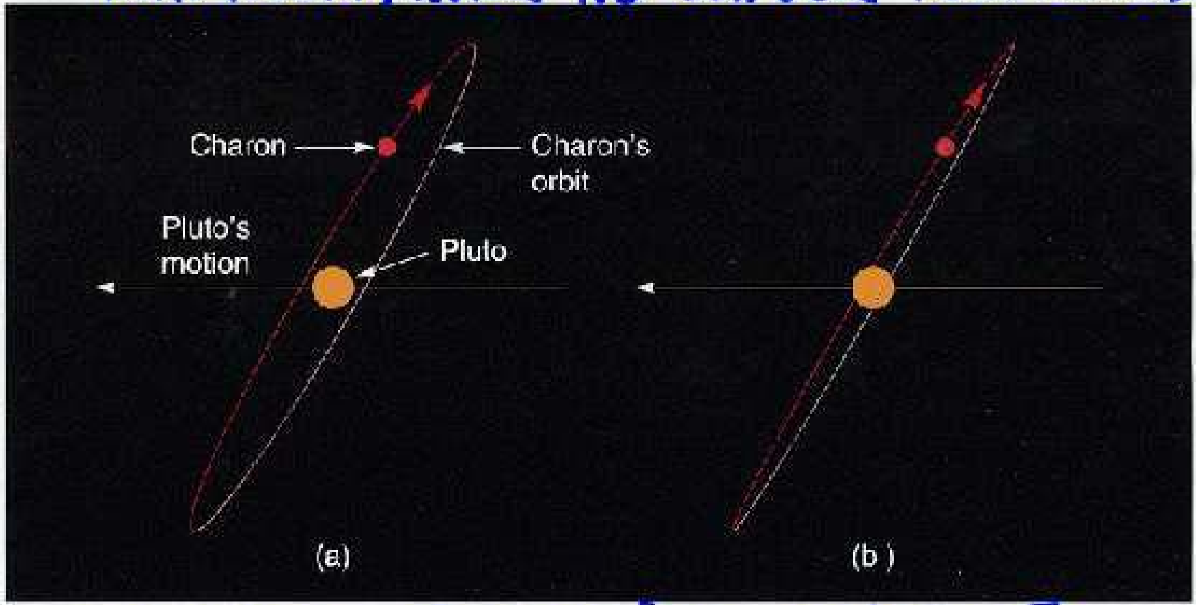
HEAT DEATH OF THE UNCHANGING UNIVERSE : ALL MATTER REACHES SAME TEMP., ENTROPY REACHES MAXIMUM, WORK NO LONGER PERFORMED.

Charon's orbit around



IN ACTUAL EXPANDING UNIVERSE, HEAT DEATH UNREALISTIC ; UNIVERSE MAY EVEN COLLAPSE

[illegible]

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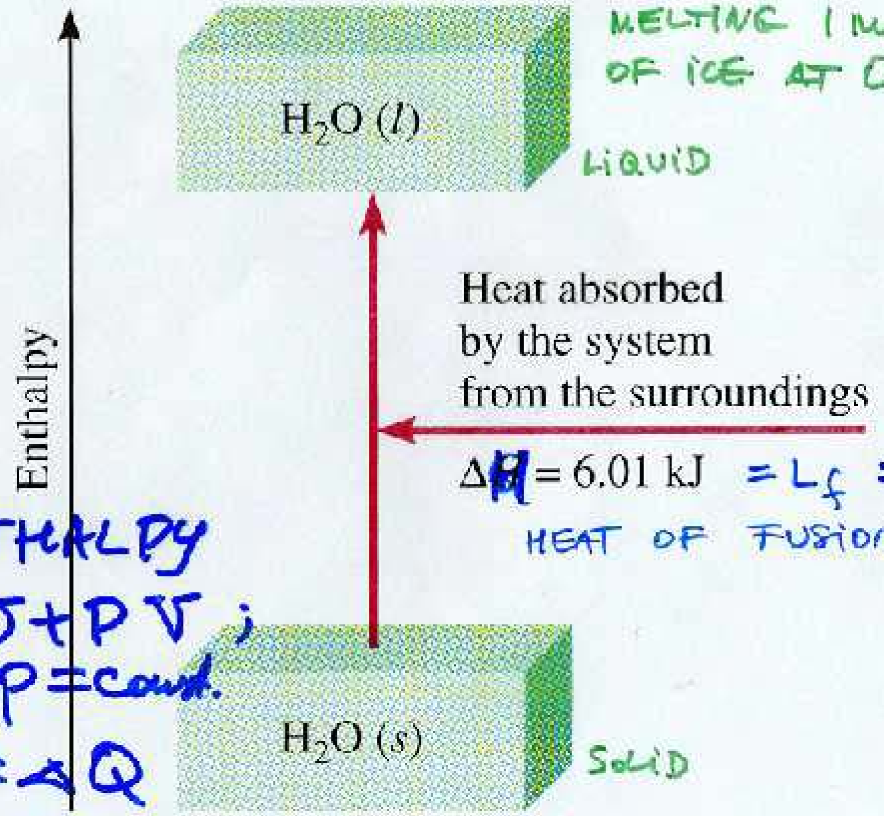

MELTING 1 MOLE OF ICE AT 0°C

LIQUID

SOLID

$= L_f = \Delta Q$

HEAT OF FUSION

ENTHALPY

$H = U + PV$ ;

AT $P =$ const.

$\Delta H = \Delta Q$

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Figure 6.4