Final

Physics 101: Lecture 28
Thermodynamics II

- Today's lecture will cover Textbook Chapter 15.6-15.9

Check Final Exam Room Assignment! Bring ID!

Be sure to check your gradebook!

Final Exam Info!!

- ~ 45 Problems
- Roughly even distribution over lectures
- Study
  - ➔ Old hour exams
  - ➔ Discussion Quizzes
  - ➔ Homework
  - ➔ Practice problems

Recap:

➔ 1st Law of Thermodynamics

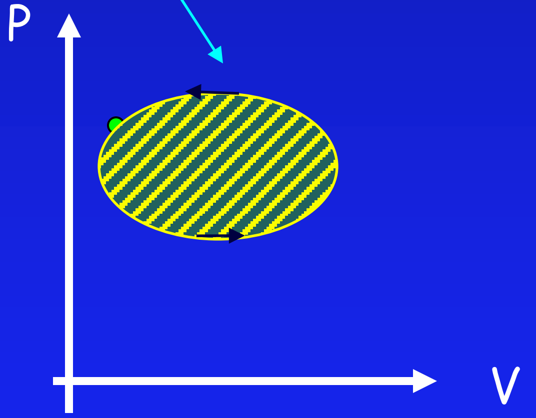
➔ energy conservation

$$Q = \Delta U - W$$

Work done on system

Increase in internal energy of system

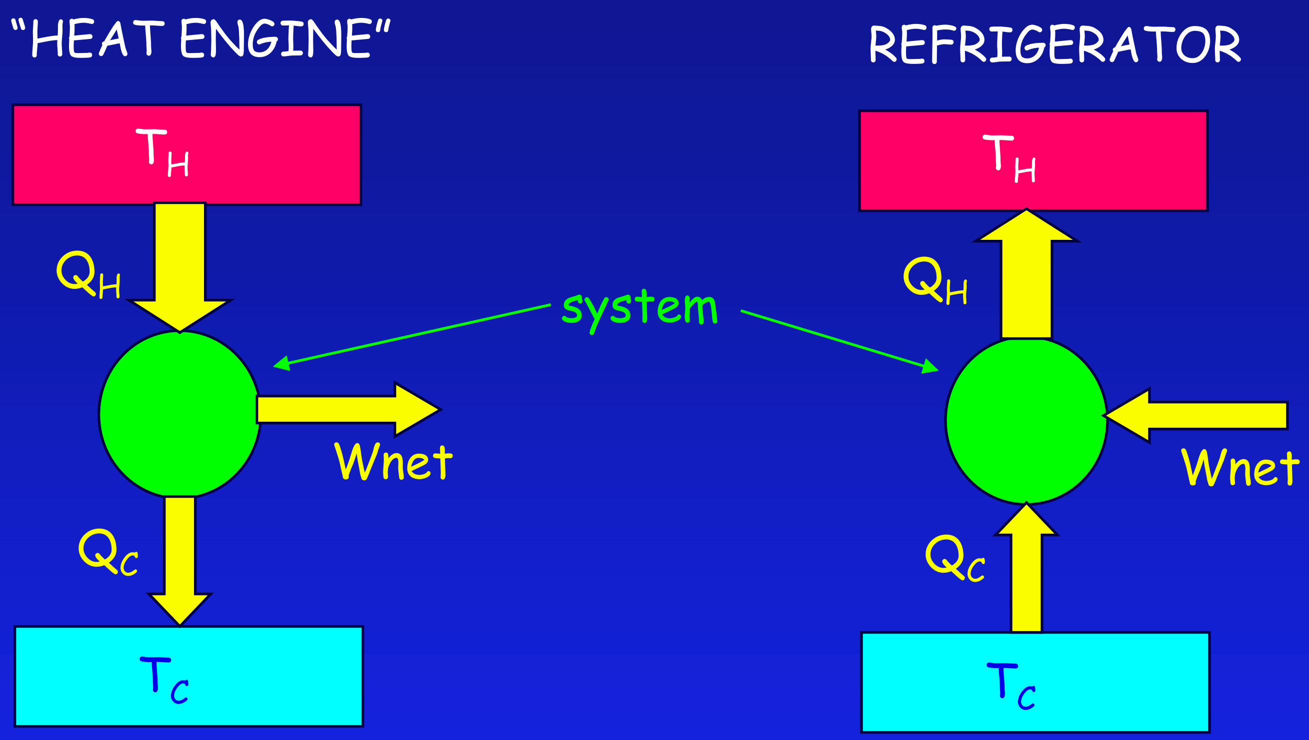
Heat flow into system



- U depends only on T ($U = 3nRT/2 = 3pV/2$)
- point on p-V plot completely specifies state of system ($pV = nRT$)
- work done is area under curve
- for complete cycle

$$\Delta U = 0 \Rightarrow Q = -W$$

Engines and Refrigerators



- system taken in closed cycle $\Rightarrow \Delta U_{system} = 0$
- therefore, net heat absorbed = work done by system

$Q_H - Q_C$ = -Won (engine) = Wby = Wnet

$Q_C - Q_H$ = -Won (refrigerator) = -Wnet

energy into green blob = energy leaving green blob

Heat Engine: Efficiency

The objective: turn heat from hot reservoir into work

The cost: "waste heat"

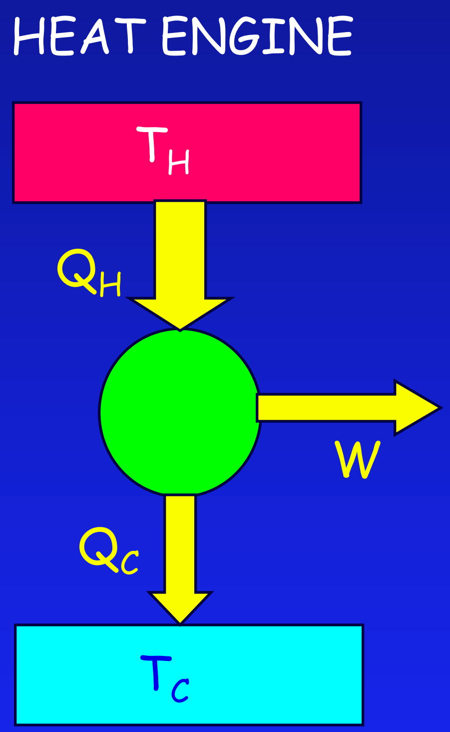
1st Law: $Q_H - Q_C = W$

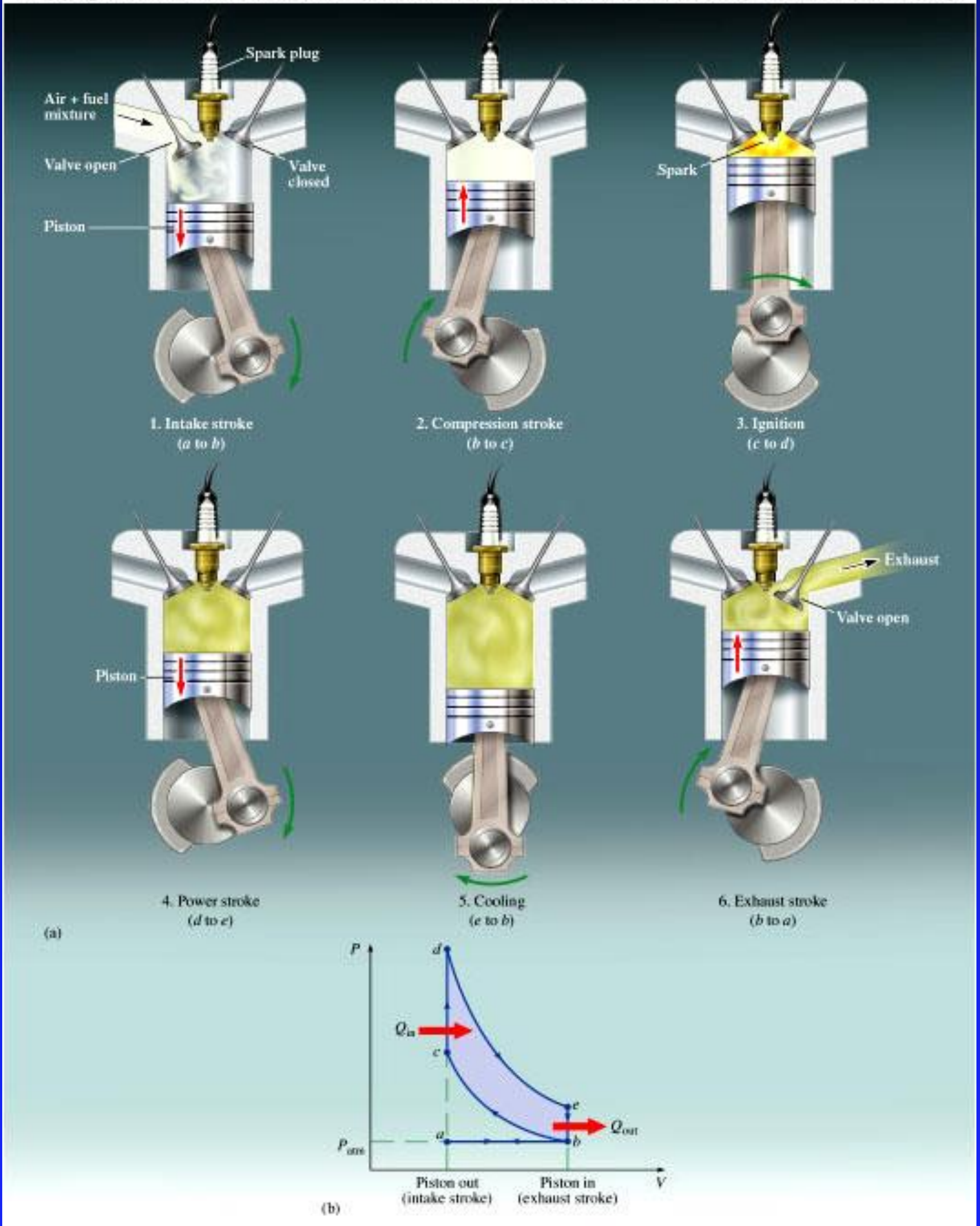
efficiency $e \equiv W/Q_H$

$= W/Q_H$

$= (Q_H - Q_C)/Q_H$

$= 1 - Q_C/Q_H$



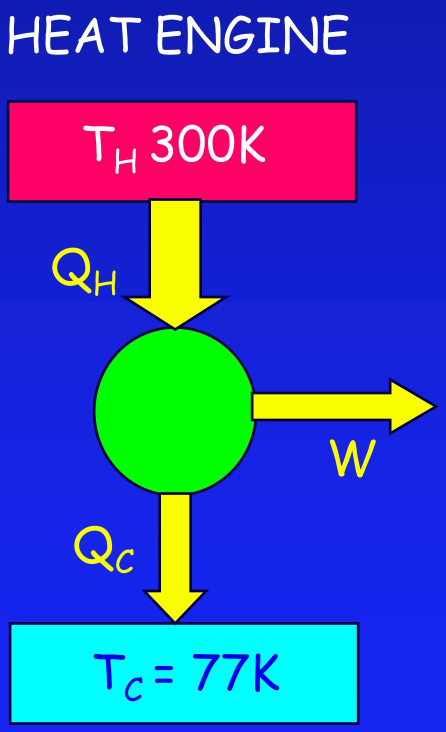

Spark plug
Air + fuel mixture
Valve open
Valve closed
Piston
1. Intake stroke (a to b)
2. Compression stroke (b to c)
Spark
3. Ignition (c to d)
Piston
4. Power stroke (d to e)
5. Cooling (e to b)
Exhaust
Valve open
6. Exhaust stroke (b to a)
(a)
P
d
Q_{in}
c
e
Q_{out}
a
b
P_{atm}
V
Piston out (intake stroke)
Piston in (exhaust stroke)
(b)

Heat Engine ACT

- Can you get "work" out of a heat engine, if the hottest thing you have is at room temperature?

1) Yes

2) No



Rate of Heat Exhaustion

An engine operating at 25% efficiency produces work at a rate of 0.10 MW. At what rate is heat exhausted into the surrounding?

Efficiency $e = W_{net}/Q_{in} \Rightarrow Q_{in} = W_{net}/e$

Total heat flux: $Q_{net} = Q_{in} - Q_{out}$.

The questions if about $Q_{out}/\Delta t$.

Energy conservation: $W_{net} = Q_{net}$; devide by Δt:

Rate of work production: $W_{net}/\Delta t = Q_{net}/\Delta t = (Q_{in} - Q_{out})/\Delta t$

$Q_{out}/\Delta t = Q_{in}/\Delta t - W_{net}/\Delta t = (W_{net}/e)/\Delta t - W_{net}/\Delta t =$

$= [(W_{net} - eW_{net})/e\,]/\Delta t = (W_{net}/\Delta t - eW_{net}/\Delta t)/e =$

$= (0.1MW - 0.25*0.1)/0.25 = 0.3MW$

Refrigerator: Coefficient of Performance

The objective: remove heat from cold reservoir

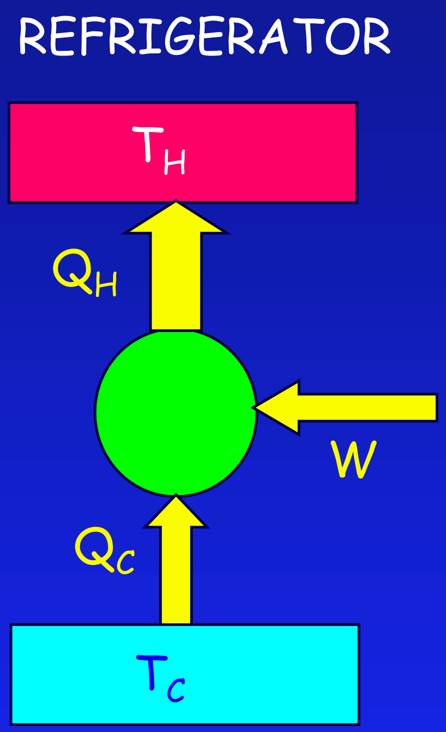
The cost: work

1st Law: $Q_H = W + Q_C$

coefficient of performance

$$K_r \equiv Q_C/W$$

$$= Q_C/(Q_H - Q_C)$$



New concept: Entropy (S)

- A measure of "disorder"
- A property of a system (just like p, V, T, U)
  - ➔ related to number of number of different "states" of system
- Examples of increasing entropy:
  - ➔ ice cube melts
  - ➔ gases expand into vacuum
- Change in entropy:
  - ➔ $\Delta S = Q/T$
    - » >0 if heat flows into system (Q>0)
    - » <0 if heat flows out of system (Q<0)

ACT

A hot (98 C) slab of metal is placed in a cool (5C) bucket of water.

$\Delta S = Q/T$

What happens to the entropy of the metal?

A) Increase B) Same C) Decreases

Heat leaves metal: $Q<0$

What happens to the entropy of the water?

A) Increase B) Same C) Decreases

Heat enters water: $Q>0$

What happens to the total entropy (water+metal)?

A) Increase B) Same C) Decreases

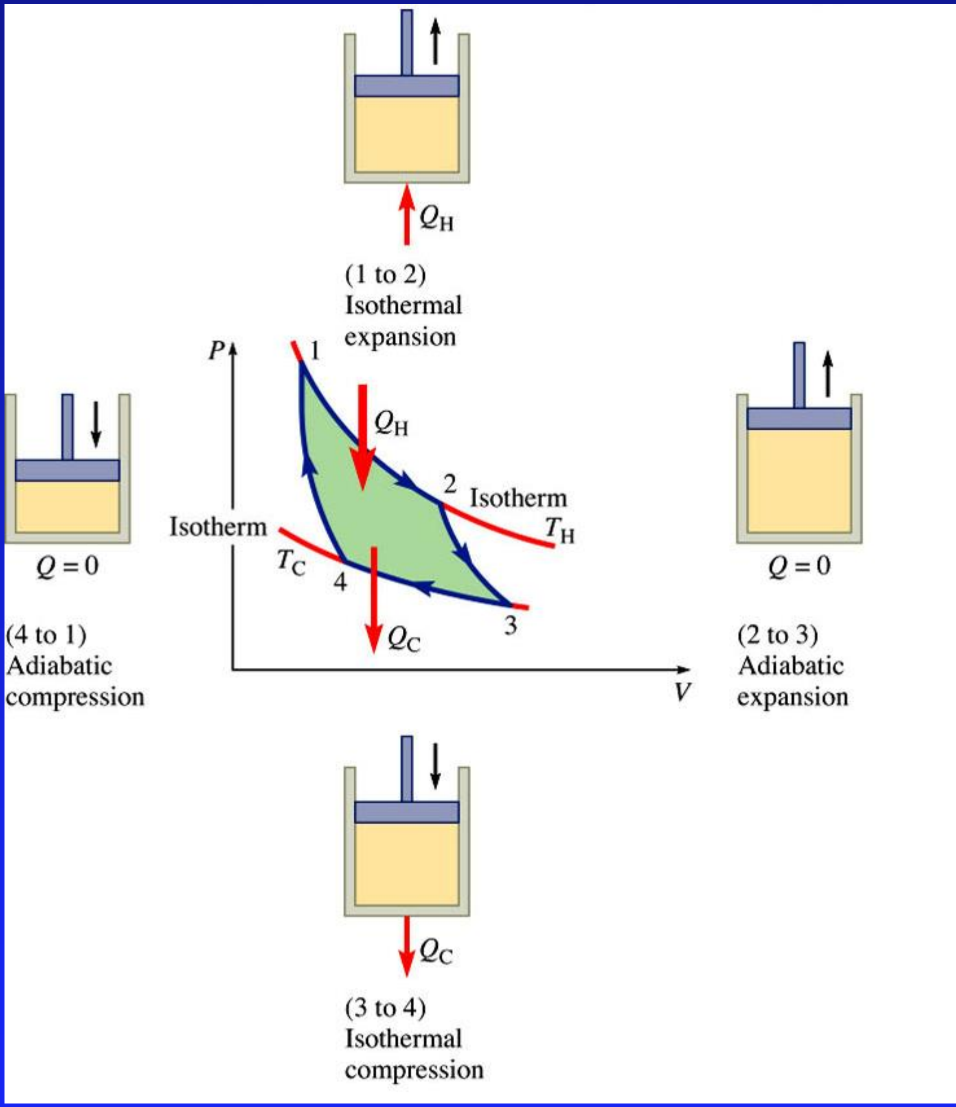
$\Delta S = Q/T_{water} - Q/T_{metal}$

Second Law of Thermodynamics

- The entropy change (Q/T) of the system+environment ≥ 0
  - ➔ never < 0
  - ➔ order to disorder
- Consequences
  - ➔ A "disordered" state cannot spontaneously transform into an "ordered" state
  - ➔ No engine operating between two reservoirs can be more efficient than one that produces 0 change in entropy. This is called a "Carnot engine"

Carnot Cycle

- Idealized Heat Engine
  - ➔ No Friction
  - ➔ $\Delta S = Q/T = 0$
  - ➔ Reversible Process
    - » Isothermal Expansion
    - » Adiabatic Expansion
    - » Isothermal Compression
    - » Adiabatic Compression



Engines and the 2nd Law

The objective: turn heat from hot reservoir into work

The cost: "waste heat"

1st Law: $Q_H - Q_C = W$

efficiency $e \equiv W/Q_H = W/Q_H = 1 - Q_C/Q_H$

$\Delta S = Q_C/T_C - Q_H/T_H \geq 0$

$\Delta S = 0$ for Carnot

Therefore, $Q_C/Q_H \geq T_C/T_H$

$Q_C/Q_H = T_C/T_H$ for Carnot

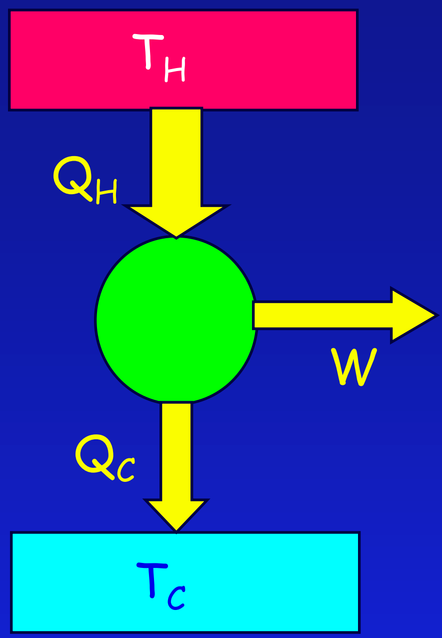
Therefore $e = 1 - Q_C/Q_H \leq 1 - T_C/T_H$

$e = 1 - T_C/T_H$ for Carnot

$e = 1$ is forbidden!

e largest if $T_C \ll T_H$

HEAT ENGINE

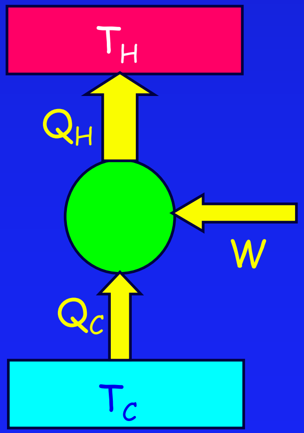


Example

Consider a hypothetical refrigerator that takes 1000 J of heat from a cold reservoir at 100K and ejects 1200 J of heat to a hot reservoir at 300K.

Answers:

1. How much work does the refrigerator do? — 200 J
2. What happens to the entropy of the universe? — Decreases
3. Does this violate the 2nd law of thermodynamics? — yes



$Q_C = 1000$ J

$Q_H = 1200$ J

Since $Q_C + W = Q_H$, $W = 200$ J

$\Delta S_H = Q_H/T_H = (1200\ J) / (300\ K) = 4\ J/K$

$\Delta S_C = -Q_C/T_C = (-1000\ J) / (100\ K) = -10\ J/K$

$\Delta S_{TOTAL} = \Delta S_H + \Delta S_C = -6\ J/K$ ➔ decreases (violates 2nd law)

Prelecture

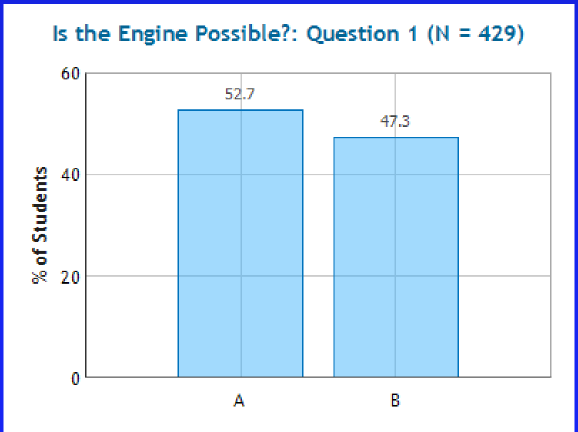
Consider a hypothetical device that takes 1000 J of heat from a hot reservoir at 300K, ejects 200 J of heat to a cold reservoir at 100K, and produces 800 J of work.

Does this device violate **the second law** of thermodynamics ?

1. Yes ← correct
2. No

total entropy decreases.

$$\Delta S_H = Q_H/T_H = (-1000\text{ J}) / (300\text{ K}) = -3.33\text{ J/K}$$
$$\Delta S_C = +Q_C/T_C = (+200\text{ J}) / (100\text{ K}) = +2\text{ J/K}$$
$$\Delta S_{TOTAL} = \Delta S_H + \Delta S_C = -1.33\text{ J/K} \rightarrow \text{(violates 2}^{nd}\text{ law)}$$

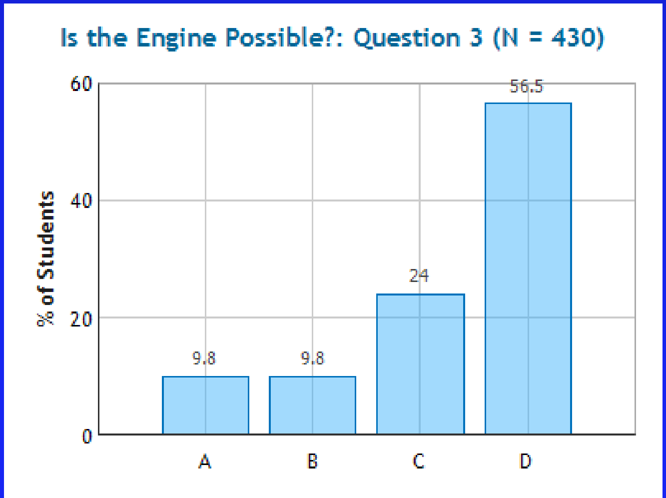


- $W (800) = Q_{hot} (1000) - Q_{cold} (200)$
- $\text{Efficiency} = W/Q_{hot} = 800/1000 = 80\%$
- $\text{Max eff} = 1 - T_c/T_h = 1 - 100/300 = 67\%$

Prelecture 3

Which of the following is forbidden by the second law of thermodynamics?

1. Heat flows into a gas and the temperature falls
2. The temperature of a gas rises without any heat flowing into it
3. Heat flows spontaneously from a cold to a hot reservoir
4. All of the above



Answer: 3

Summary

- **First Law** of thermodynamics: Energy Conservation
  - ➔ $Q = \Delta U - W$
- Heat Engines
  - ➔ Efficiency = = $1 - Q_C/Q_H$
- Refrigerators
  - ➔ Coefficient of Performance = $Q_C/(Q_H - Q_C)$
- Entropy $\Delta S = Q/T$
- **Second Law**: Entropy always increases!
- Carnot Cycle: Reversible, Maximum Efficiency $e = 1 - T_c/T_h$