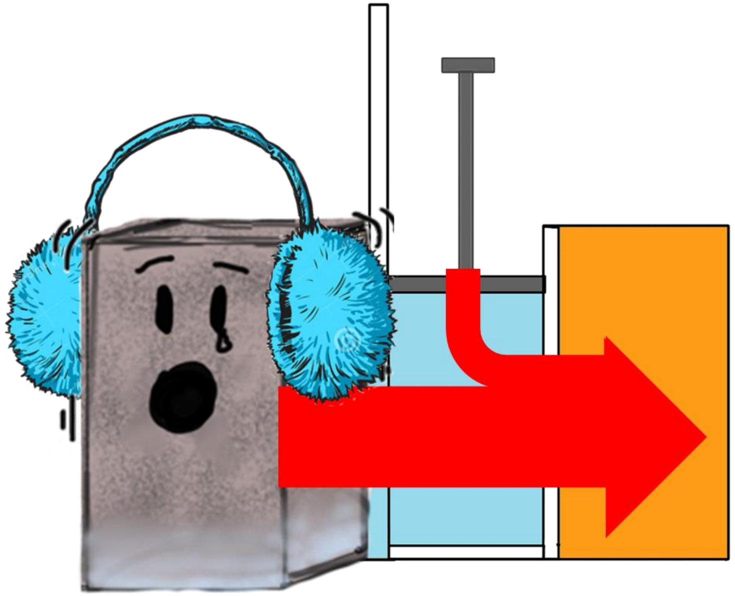
Lecture 20.

Diesel engines. Refrigerators.



Toolkit

- n : use $PV = nRT$ (always)
- The following equations are generally used for constant n:
  - $T, V,$ or P : use $\frac{PV}{T} = \text{constant}$ (always)

    $\frac{P}{T} = \text{constant}$ (const V) $\quad \frac{V}{T} = \text{constant}$ (const P) $\quad PV = \text{constant}$ (const T)

    $PV^{\gamma} = \text{constant}$ (adiabatic) $\quad TV^{\gamma-1} = \text{constant}$ (adiabatic)

  - ΔU : have $\Delta U = nC_v\Delta T$ (always)
  - W : have $W = \int_{V_i}^{V_f} P(V)\,dV$ (always)

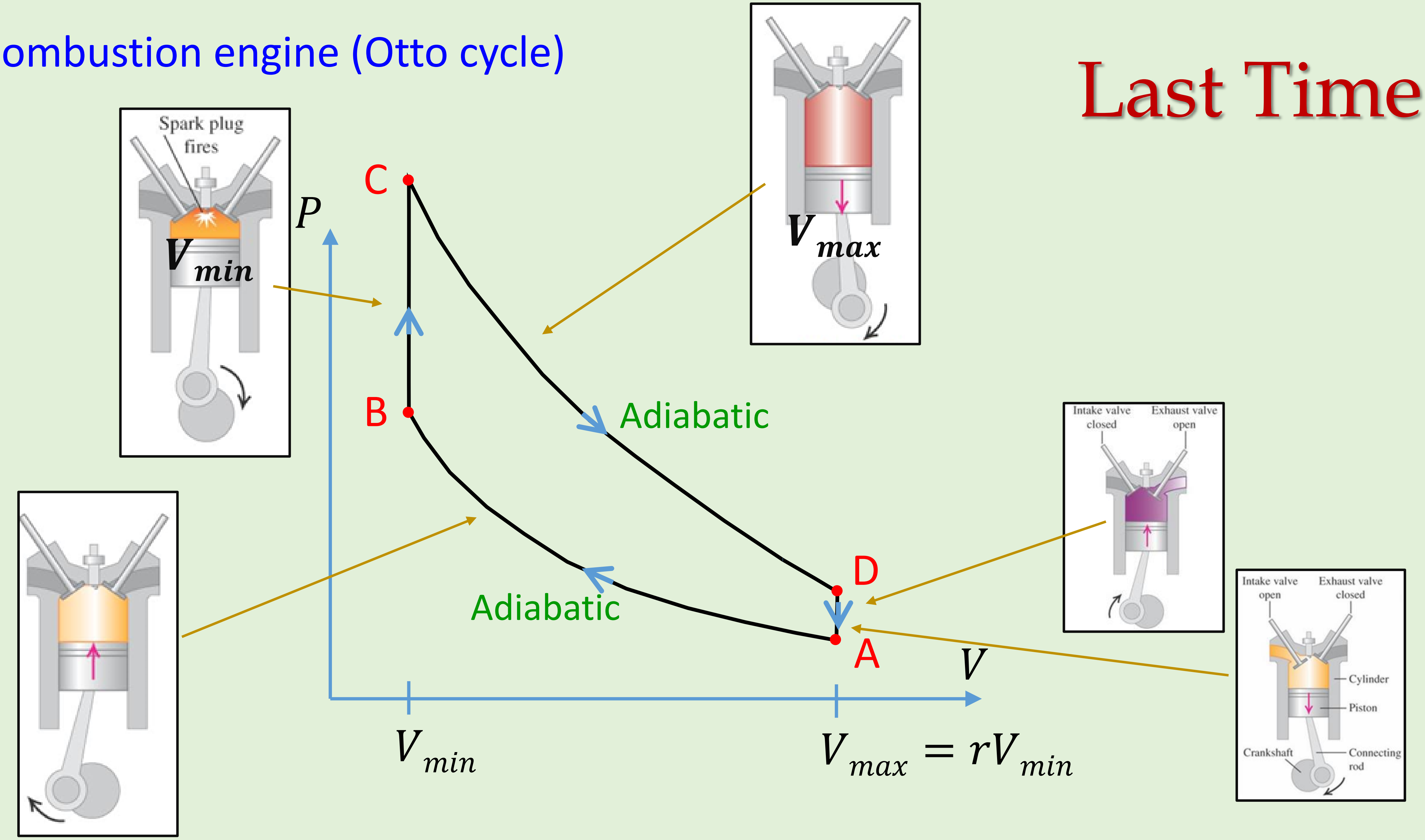
    $W = 0$ (const V) $\quad W = P\Delta V$ (const P) $\quad W = nRT\ln\left(\frac{V_f}{V_i}\right)$ (const T)

  - Q : use $Q = \Delta U + W$ (always)

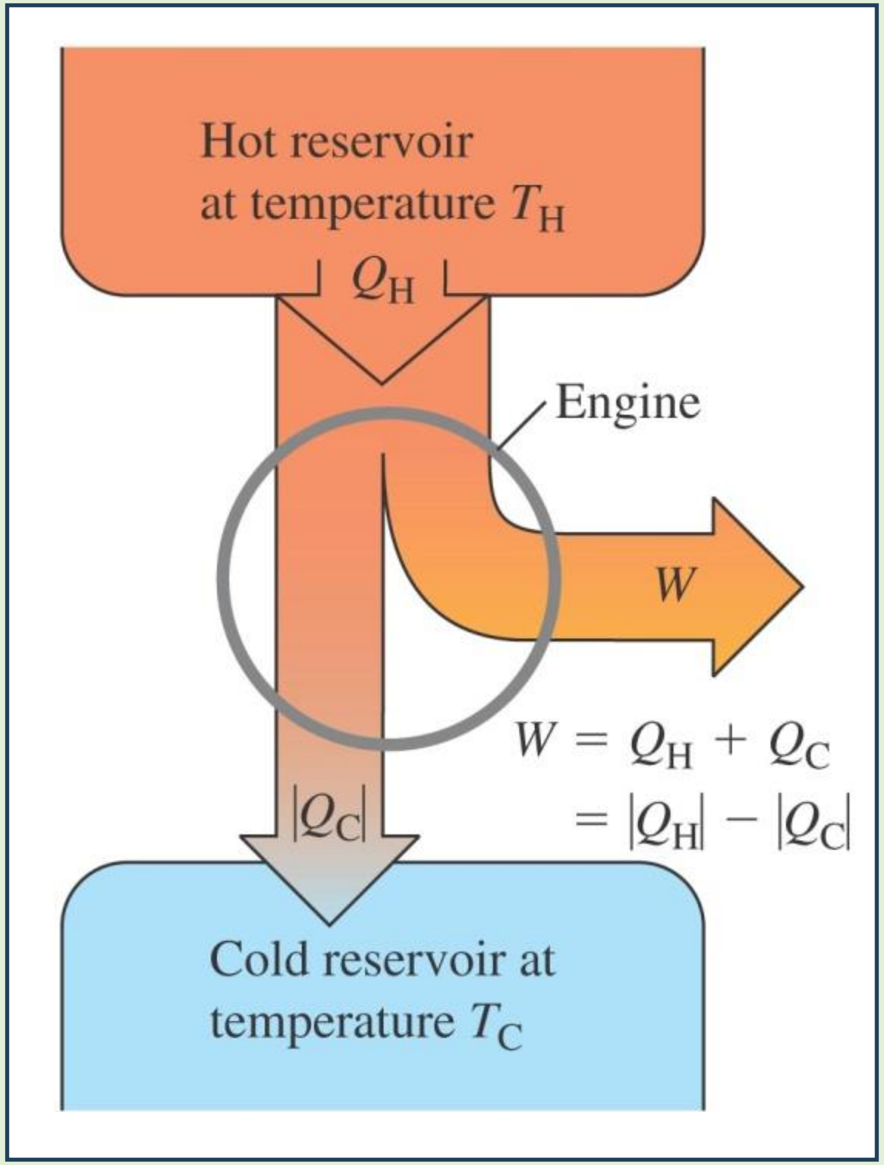
    $Q = nC_v\Delta T$ (const V) $\quad Q = nC_p\Delta T$ (const P) $\quad Q = 0$ (adiabatic)

Combustion engine (Otto cycle)

Last Time



Efficiency of an Engine



- Efficiency (e) $= \dfrac{\text{net work we get out}}{\text{heat we need to supply}}$

  - Q_H: Heat absorbed by gas each cycle
  - Q_C: Heat expelled by gas each cycle
  - W: Net work done each cycle

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

$$e_{\text{Otto}} = 1 - \frac{1}{r^{\gamma-1}} \sim 38\%$$

- $r = \dfrac{V_{max}}{V_{min}} \sim 8 - 10$ with $\gamma \sim 1.22$

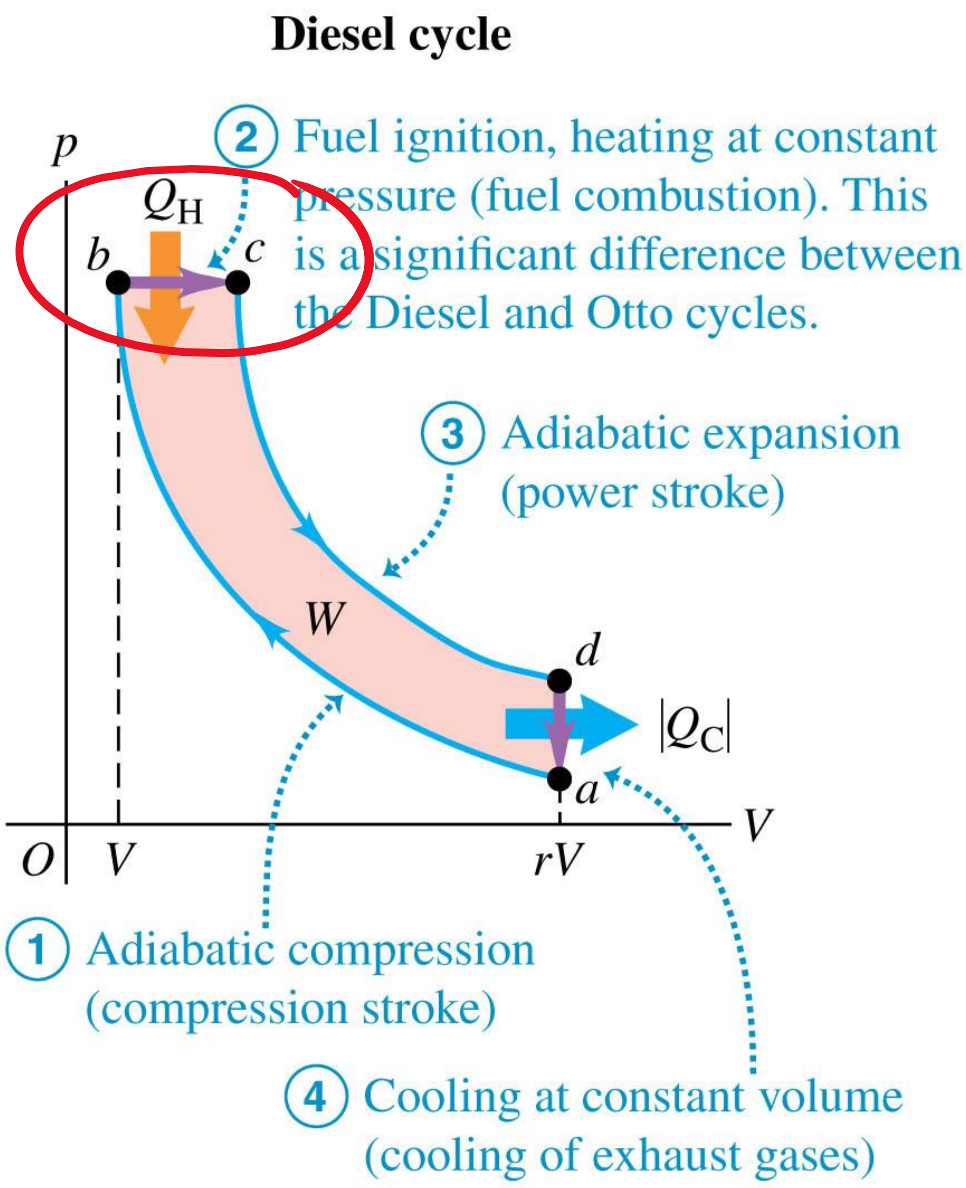
- Gasoline will spontaneously ignite if r is too large: “engine knocking” => limitations

Last Time

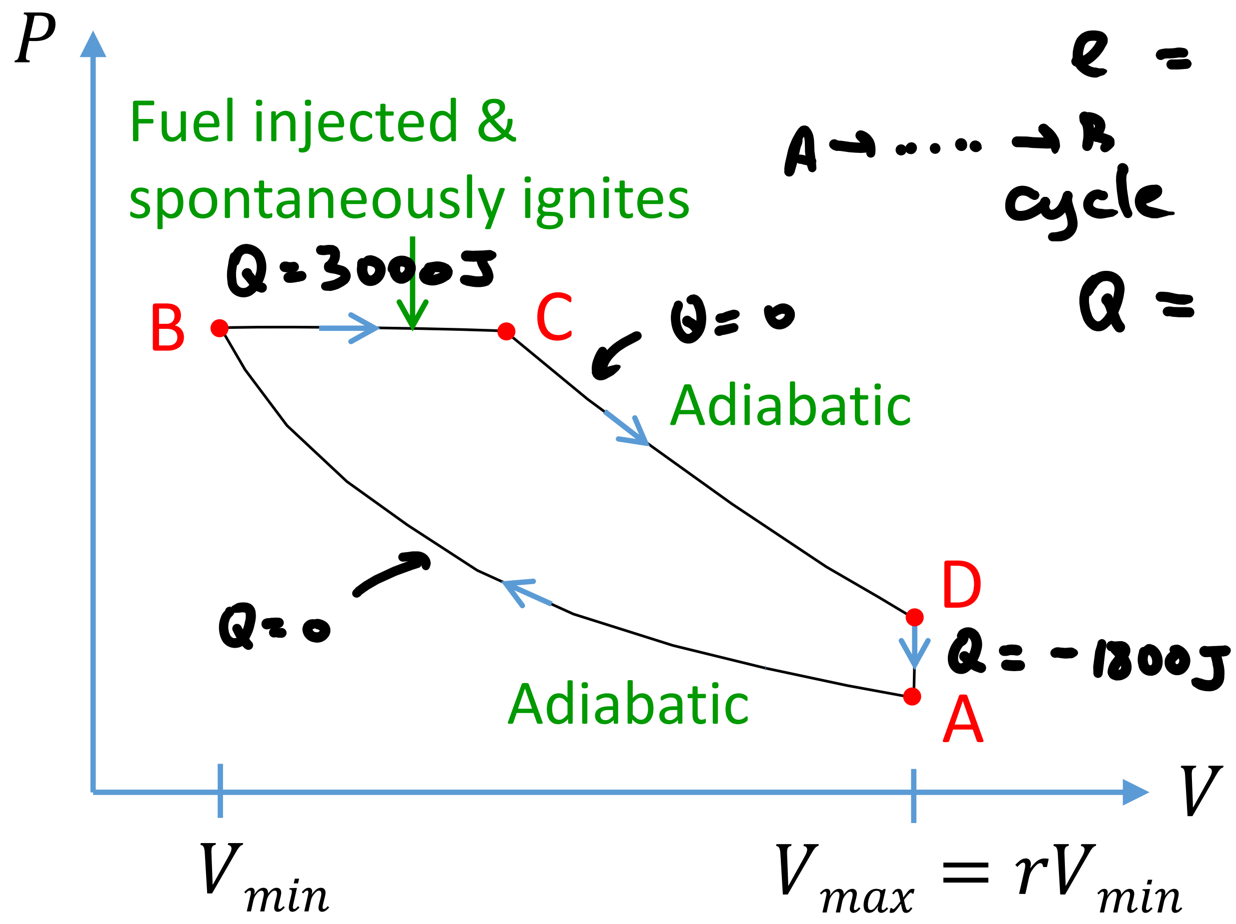
Diesel Engines

- Starting at point a, air is compressed adiabatically to point b, heated <u>at constant pressure</u> to point c, expanded adiabatically to point d, and cooled at constant volume to point a
- Because there is no fuel in the cylinder during the compression stroke, pre-ignition cannot occur, and the compression ratio r can be much higher than for a gasoline engine
- This improves efficiency
- In real diesel engines, $r \sim 15 - 23$ and $\gamma \sim 1.22$

$$\Longrightarrow \; e \sim 45\% - 50\%$$



Q: In the Diesel cycle shown, the heat added from combustion in B → C is 3,000 J while the heat expelled from the cylinder in D → A is 1,800 J. What is the efficiency of the engine?



$$e = \frac{W_{net}}{Q_{in}} = \frac{1200}{3000}$$

A → .... → B

cycle

$$Q = W + \underbrace{\cancel{\Delta U}}_{0}$$

$$W_{net} = Q_{net} =$$

$$= 3000\,J - 1800\,J$$

A. 0.375

B. 0.400

C. 0.600

D. 0.666

E. 0.866

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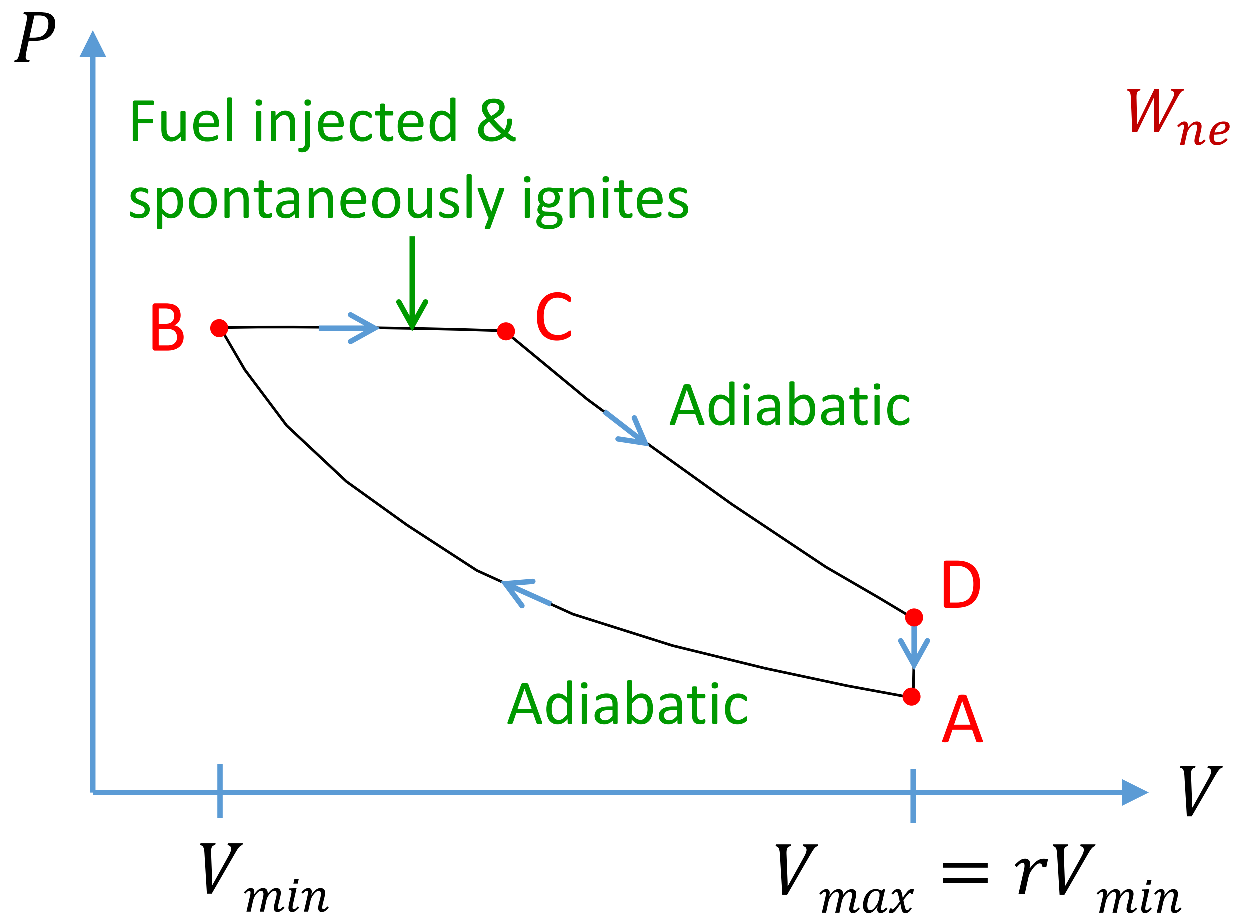


$$W_{net} = Q_{net} = 3000\,J - 1800\,J = 1200\,J$$

$$Q_{in} = 3000\,J$$

$$e = \frac{1200}{3000} = 0.4$$

A. 0.375

B. 0.400

C. 0.600

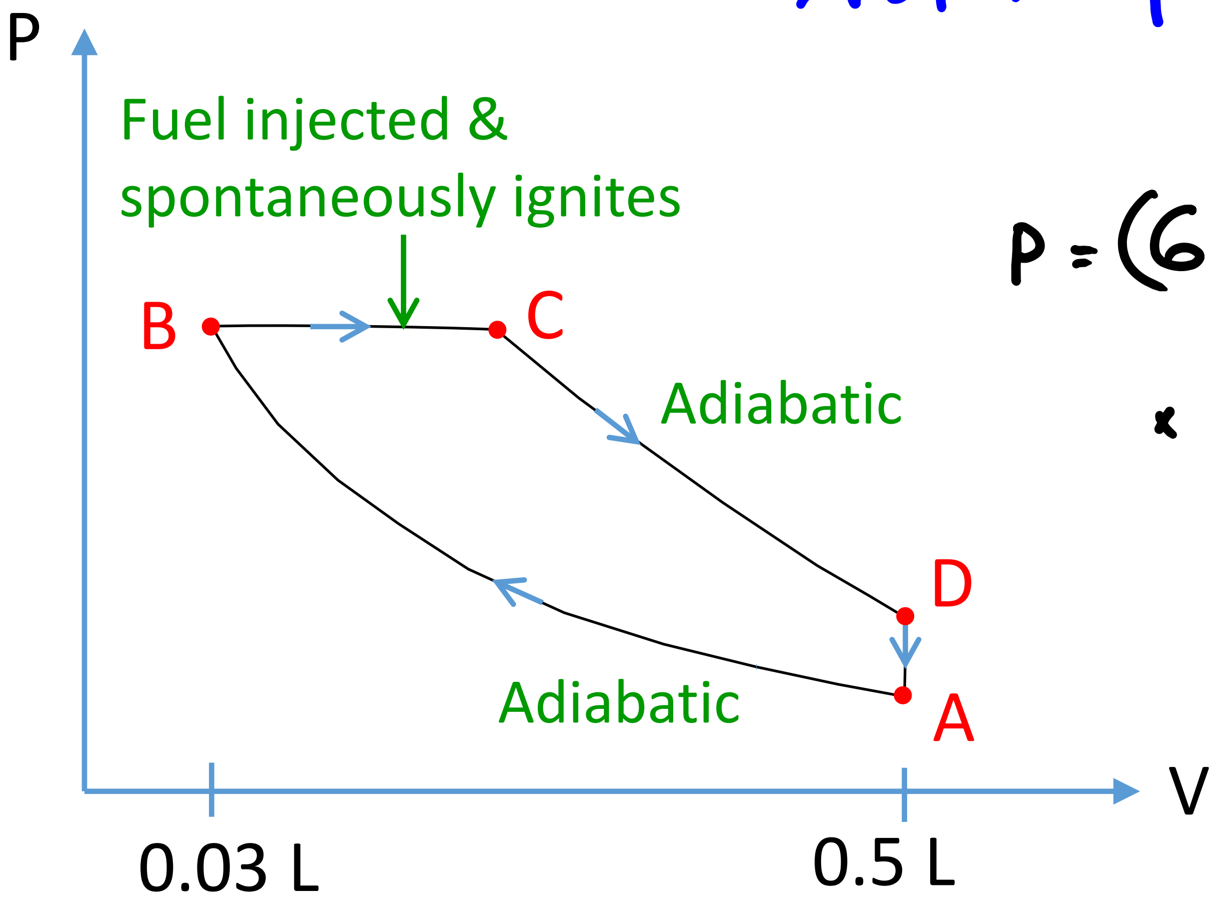
D. 0.666

E. 0.866

Q: In the Diesel cycle shown, the net work done per cycle is 1,200 J. If a car with a 6-cylinder engine is running at 3,000 rpm, how many horsepower is the engine? (1 kW = 1.33 hp)

$\underbrace{\text{rpm}}_{\text{rotation per minute}}$

NOTE: 1 cycle corresponds to 2 revolutions (useful work is only done on the compression/expansion (power stroke) revolution, not the exhaust/intake revolution)



$$P = (6 \text{ cylinders}) \times \frac{1500 \text{ cycles}}{\text{min}} \times 1200\,\text{J} \times \frac{1 \text{ min}}{60\,\text{s}} \; \frac{1.33 \text{ hp}}{1000\,\text{W}}$$

A. 120

B. 160

C. 200

D. 240

E. 300

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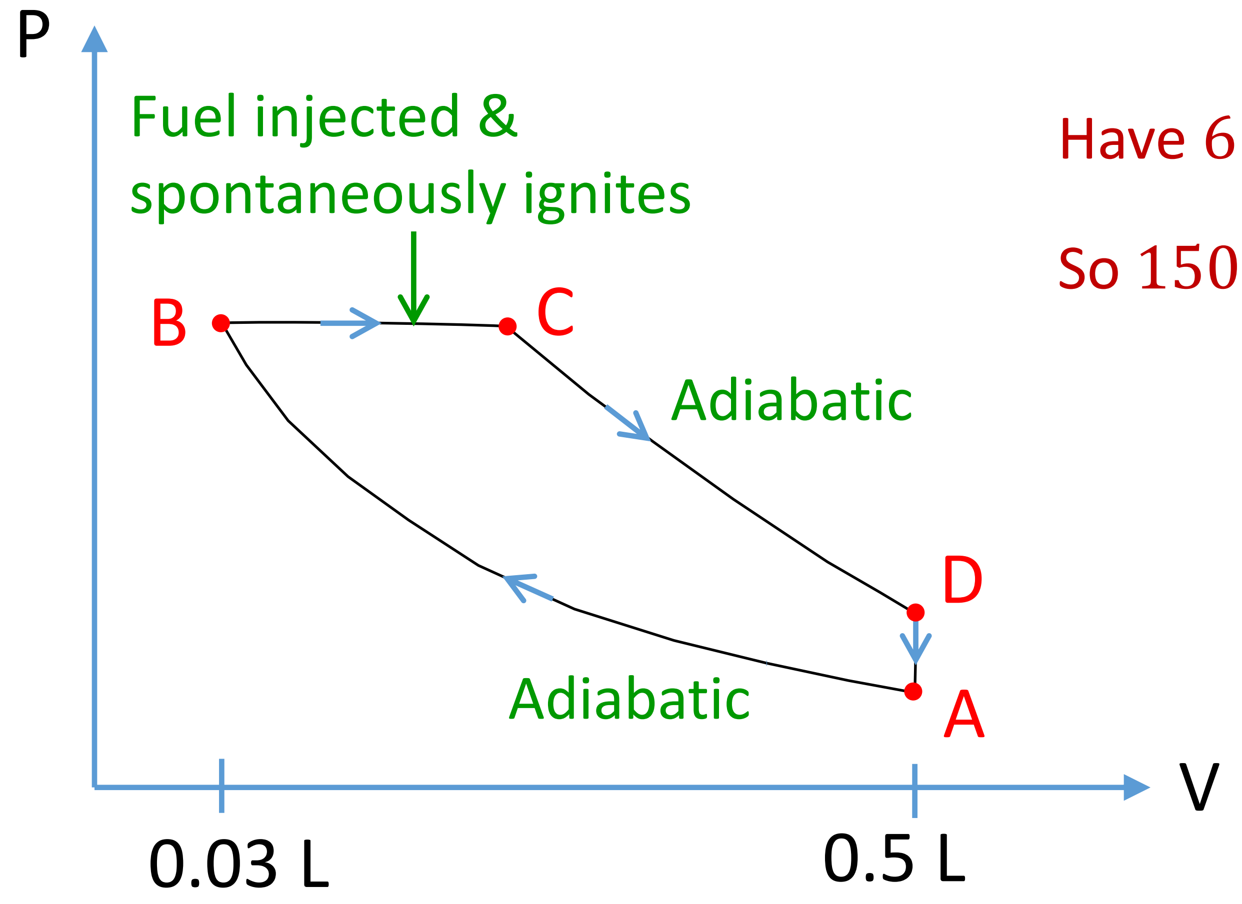


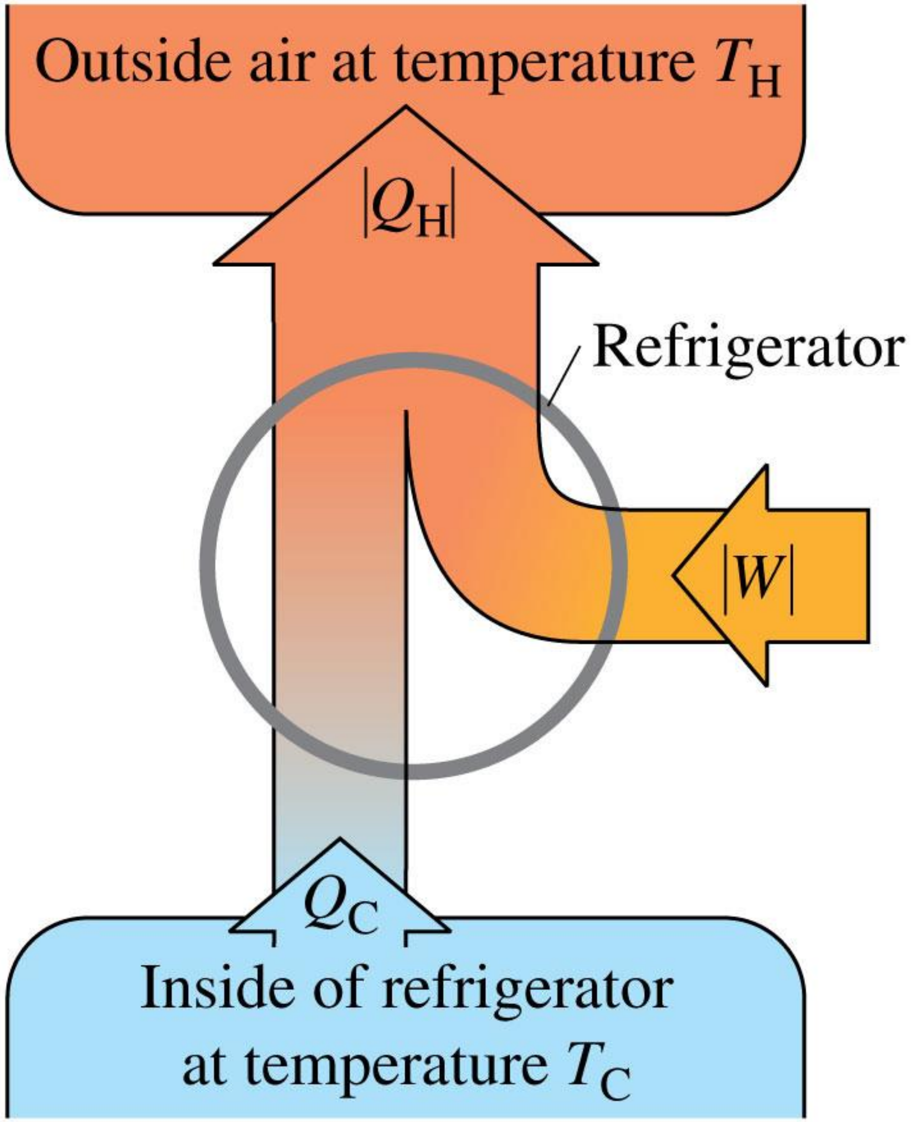
Have $6 \times \frac{1500}{60} = 150$ cycles per second

So $150 \times 1200\,J = 180{,}000\,{}^{J}/_{s} = 240\,hp$

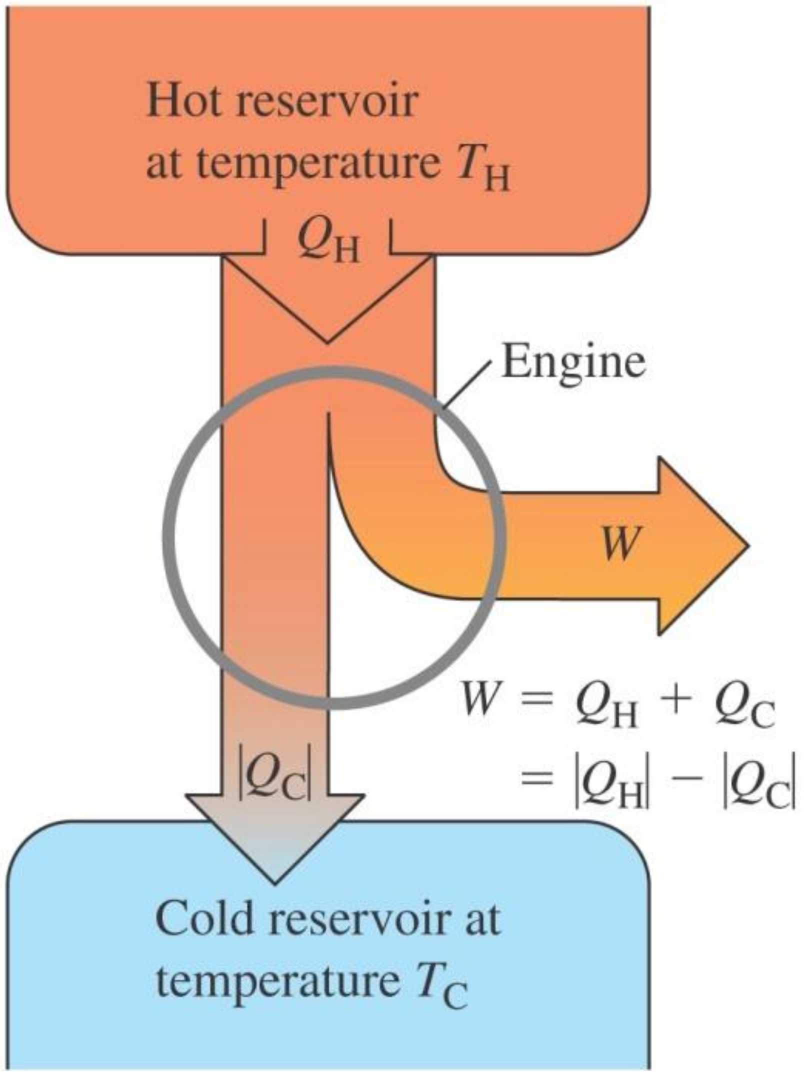
A. 120
B. 160
C. 200
D. 240
E. 300

Refrigerators

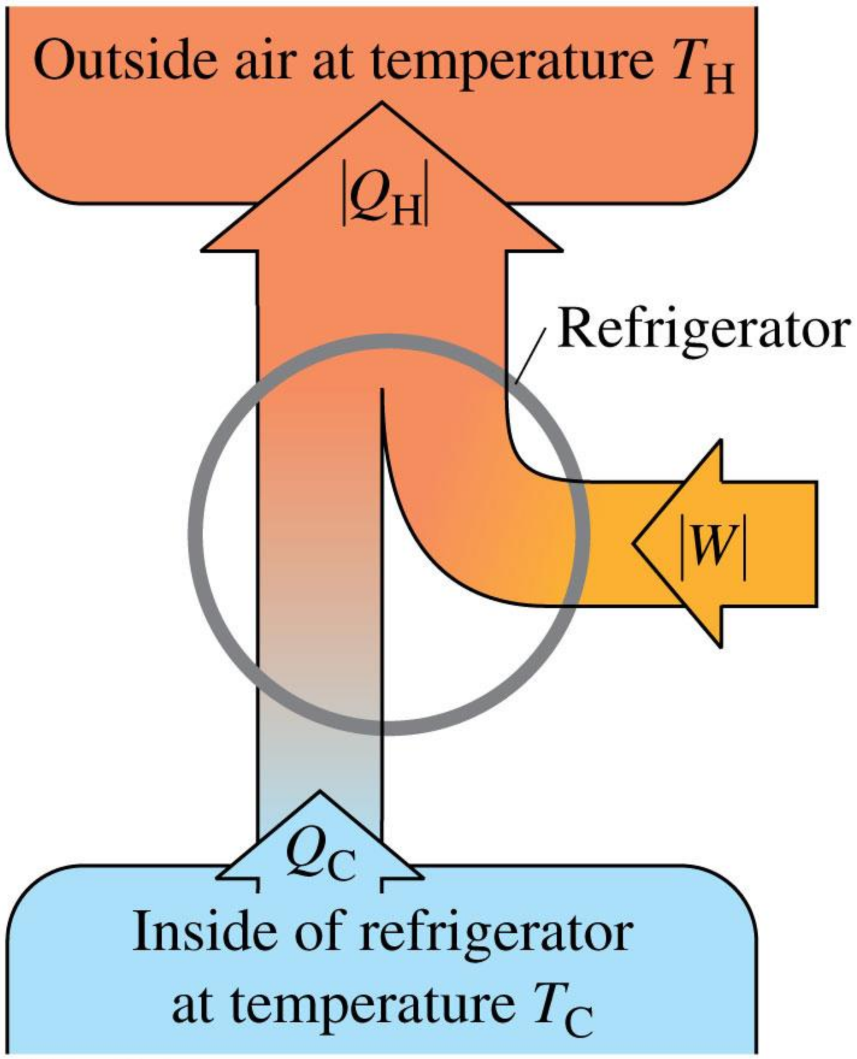
- A refrigerator takes heat from a cold place (inside the refrigerator) and gives it off to a warmer place (the room)
- An input of mechanical work is required to do this
- A refrigerator is essentially a heat engine operating in reverse



Heat Engine



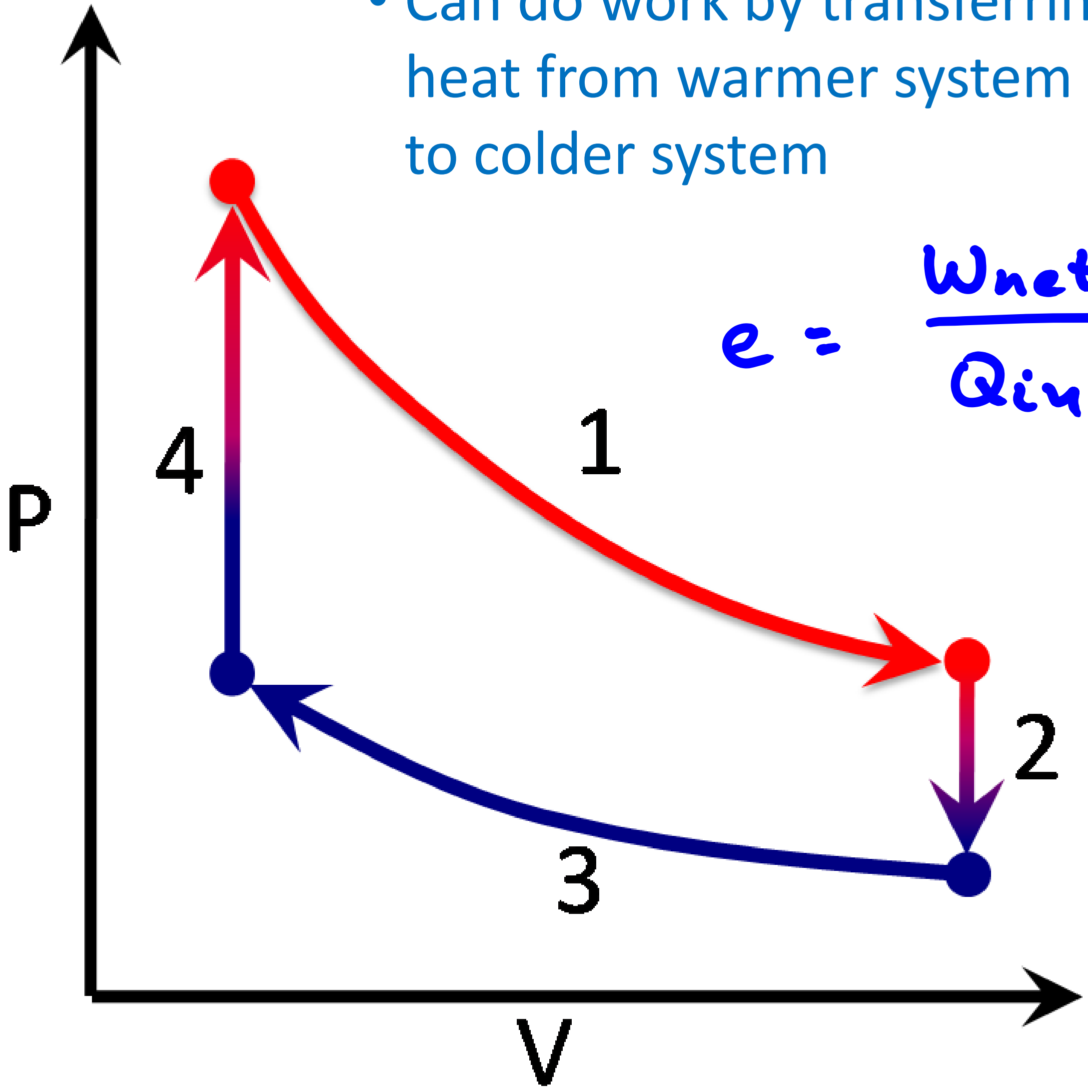
Refrigerator



“heat engine”

- Can do work by transferring heat from warmer system to colder system

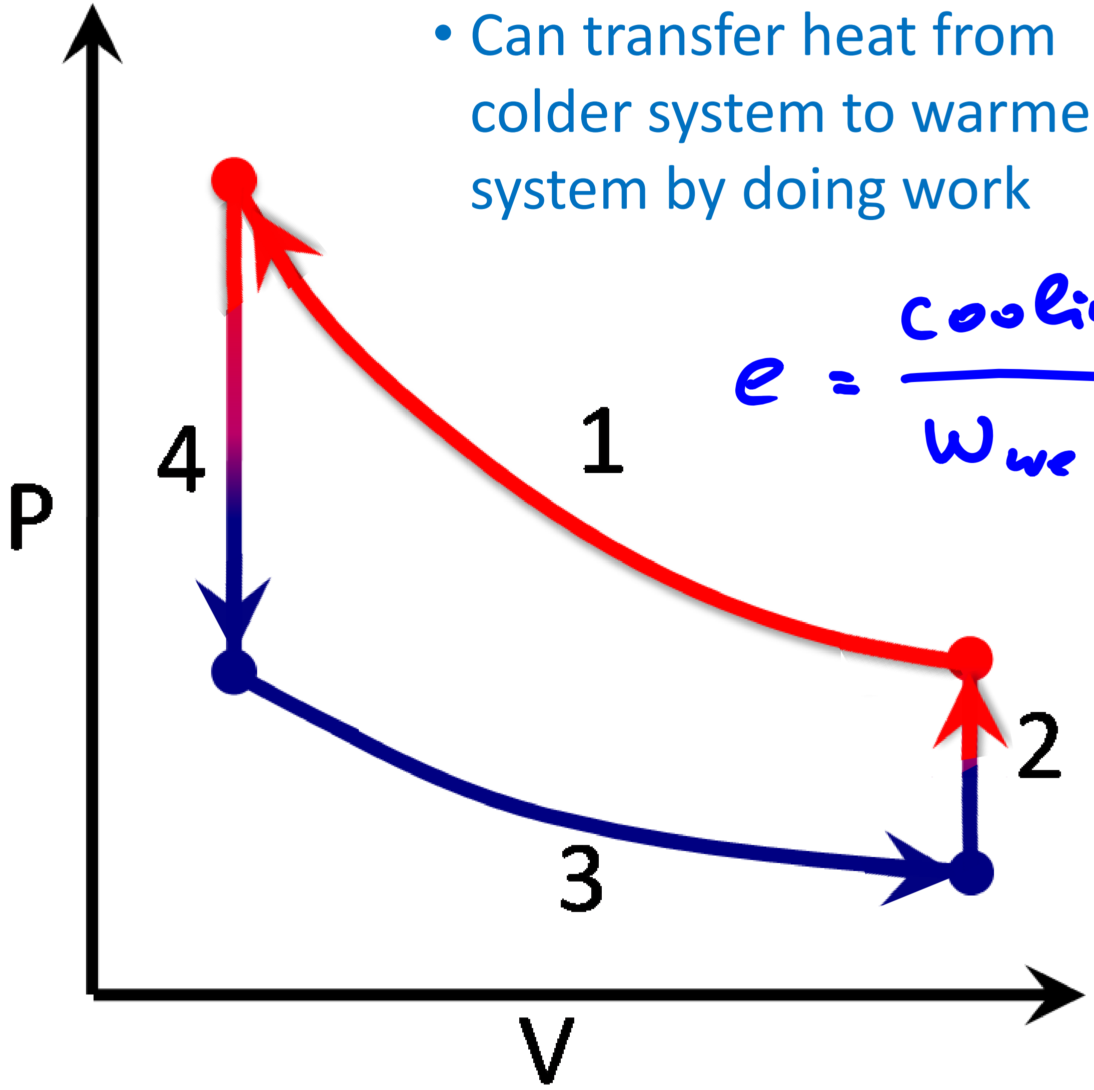
$$e = \frac{W_{net}}{Q_{in}}$$



“refrigerator: heat engine in reverse”

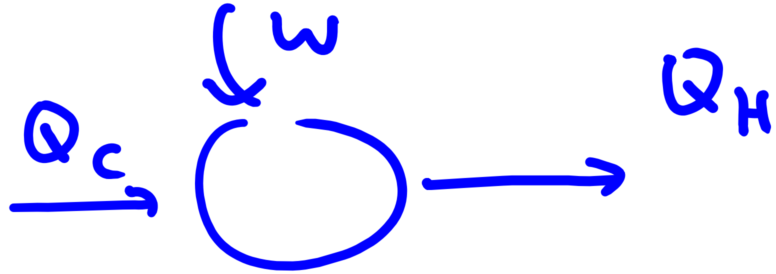
- Can transfer heat from colder system to warmer system by doing work

$$e = \frac{\text{cooling}}{W_{\text{we do}}}$$



Refrigerators: Coefficient of performance

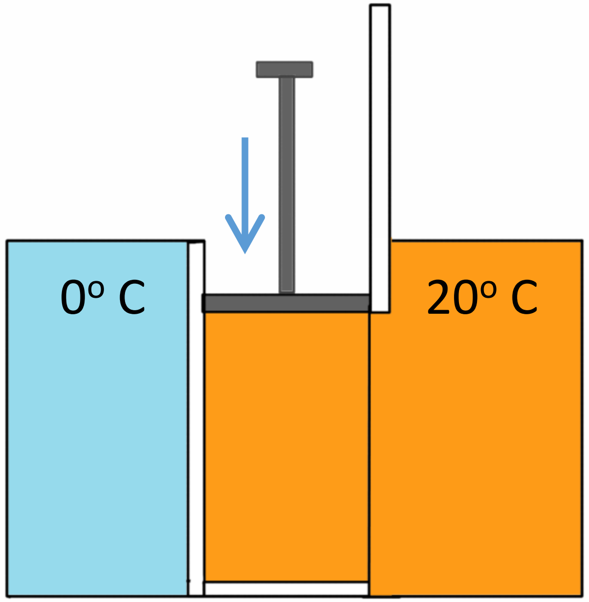
- From an economic point of view, the best refrigeration cycle is one that removes the greatest amount of heat from the inside of the refrigerator for the least expenditure of mechanical work
  - ➢ The relevant ratio is therefore $\frac{|Q_C|}{|W|}$



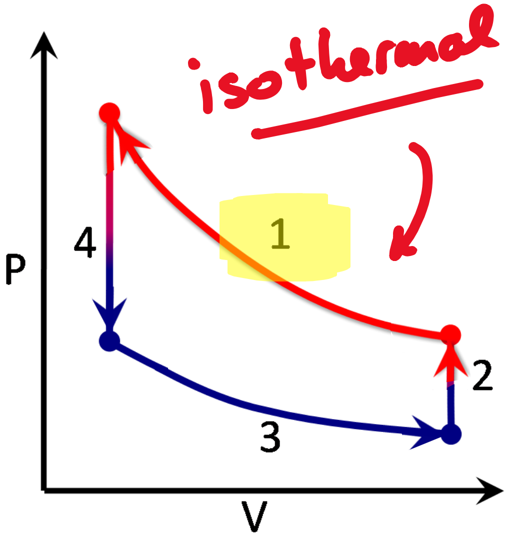
- The larger this ratio, the better the refrigerator
- We call this ratio the coefficient of performance, K:
- Coefficient of performance: $K = \frac{|Q_C|}{|W|} = \frac{\text{heat removed from inside frig}}{\text{work we put in}}$

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

- Here $|Q_H|$ is the heat rejected to the outside air



- 1 mole of nitrogen gas ($C_v = 5/2\ R$) is compressed at constant temperature $T = 20\ ^oC$ from 20 L to 5 L.
- Does heat flow in or out of the gas?
- What is Q for this process?

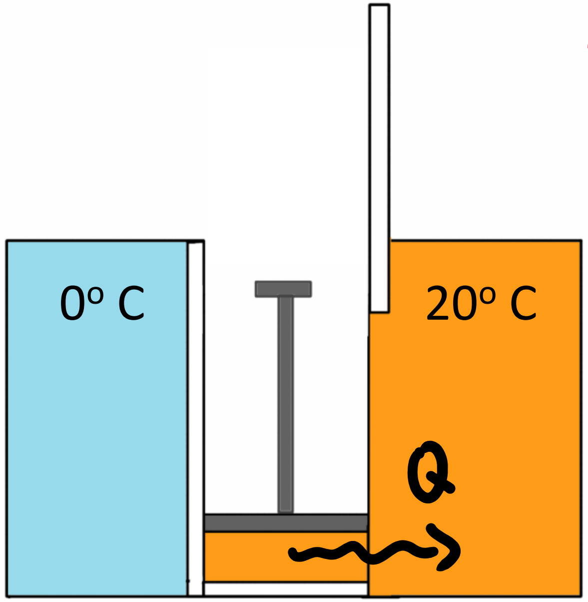


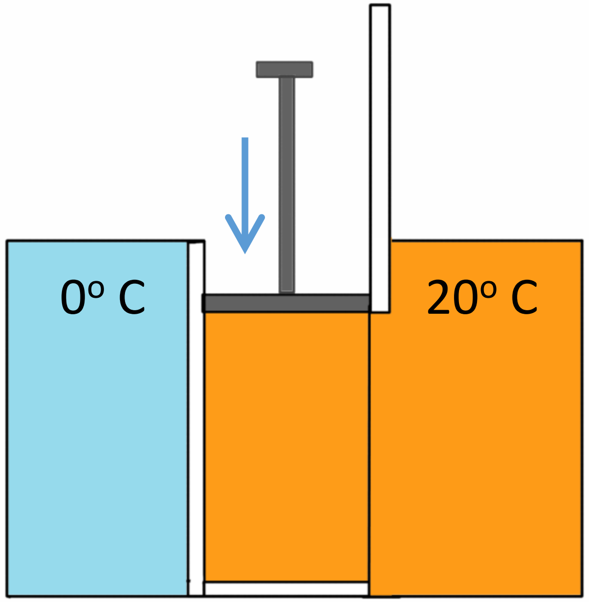
$$Q = \cancel{\Delta U} + W = nRT \ln \frac{V_f = 5L}{V_i = 20L}$$

$\Delta T = 0$

$$= (1)(8.31)(293\,K) \ln \frac{5}{20} =$$

$$= -3375\ J$$





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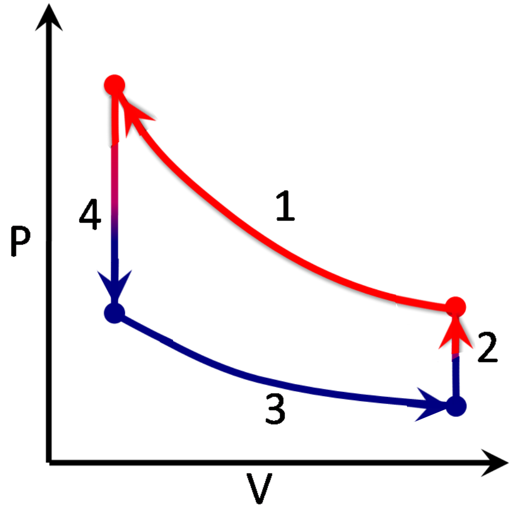
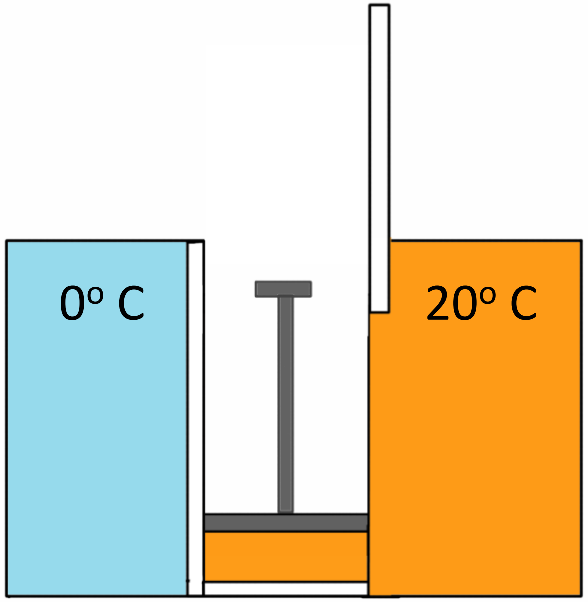
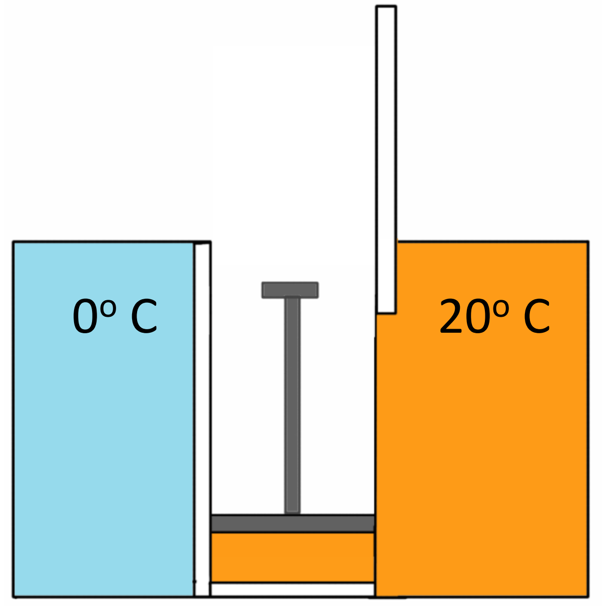




- isothermal $\Longrightarrow \Delta U = 0$
- $Q = W = nRTln\left(\frac{V_f}{V_i}\right) = -3375\ J$
- Heat goes out

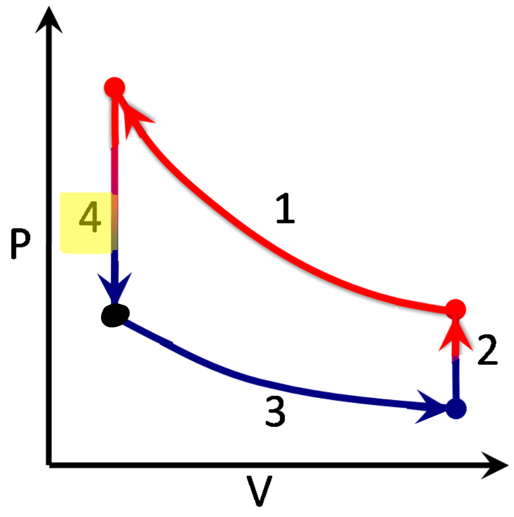


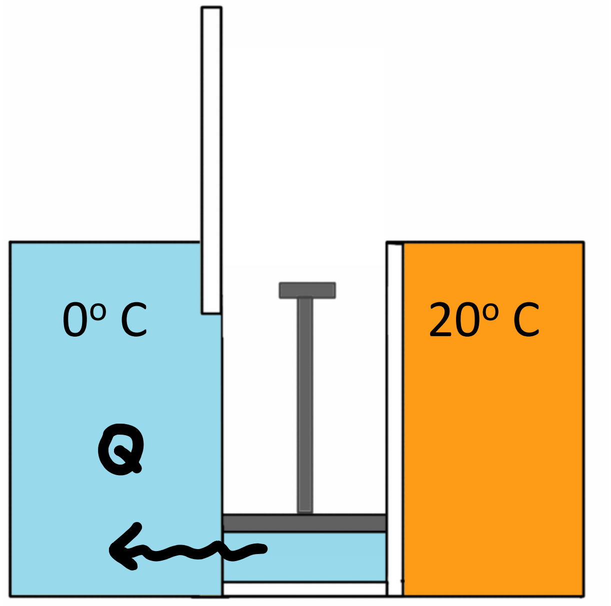
- The gas is now insulated from the warm system and put in thermal contact with the cold system, so that it cools from $T = 20\ {}^oC$ to $T = 0\ {}^oC$ at constant volume 5 L.

- What is Q for this process?

$$Q = \Delta U + \cancel{W}^{\,0} = n C_v \Delta T =$$

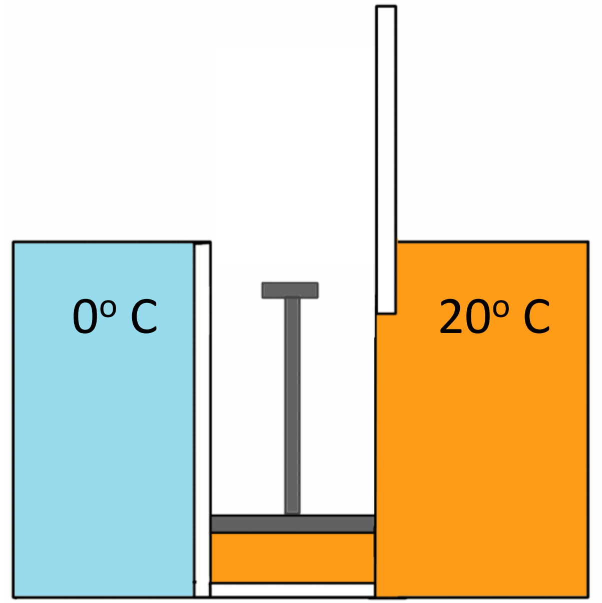
$$= (1\,\text{mole})\left(\tfrac{5}{2}\, 8.31\right)(-20) = -415\ \text{J}$$





- What is the pressure of the gas now? (recall $n = 1$ mole)

$$P = \frac{nRT}{V} = \frac{(1)(8.31)(273\text{K})}{5 \cdot 10^{-3}\ \text{m}^3} = 454\ \text{kPa}$$

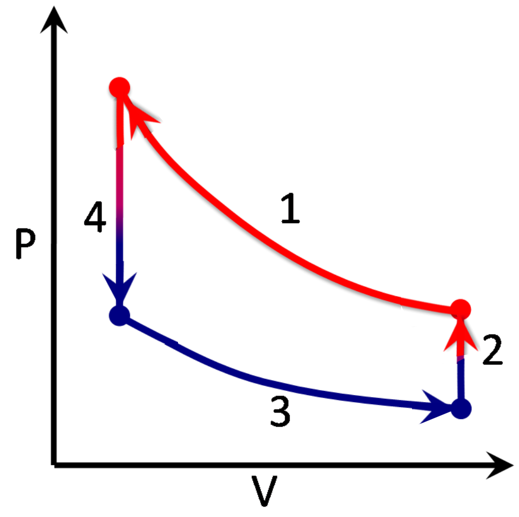


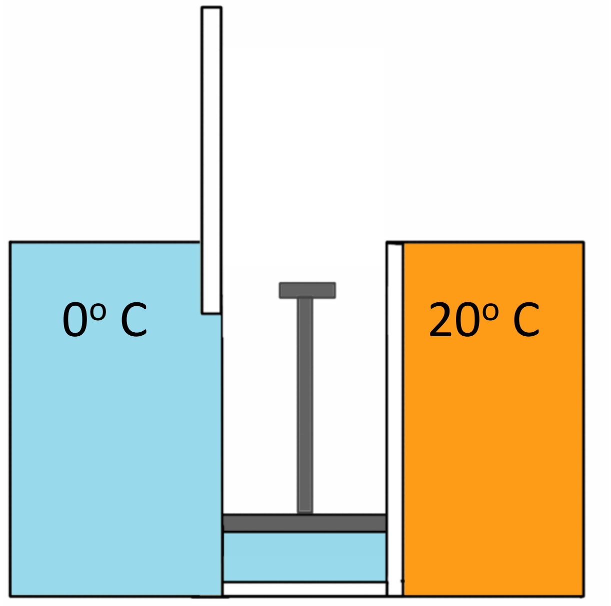
- The gas is now insulated from the warm system and put in thermal contact with the cold system, so that it cools from $T = 20\ ^oC$ to $T = 0\ ^oC$ at constant volume 5 L.

- What is Q for this process?

Constant V $\Longrightarrow W = 0$

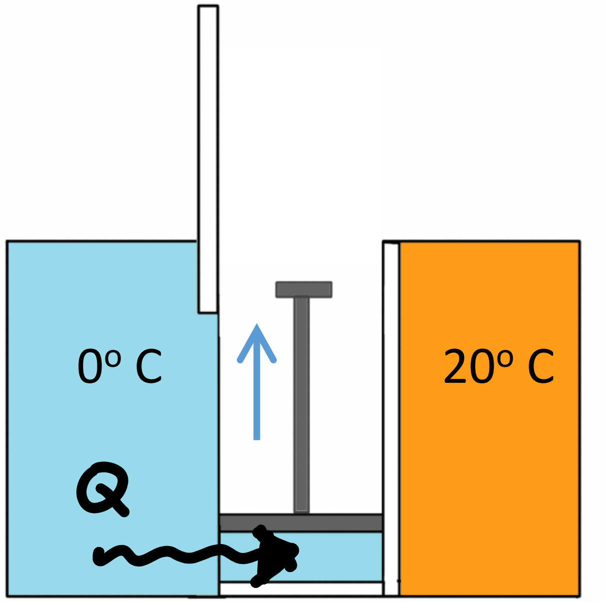
$$Q = \Delta U = nC_v\Delta T = -416\ J$$





- What is the pressure of the gas now? (recall n = 1 mole)

Use $P = \dfrac{nRT}{V} \approx 454\ kPa$



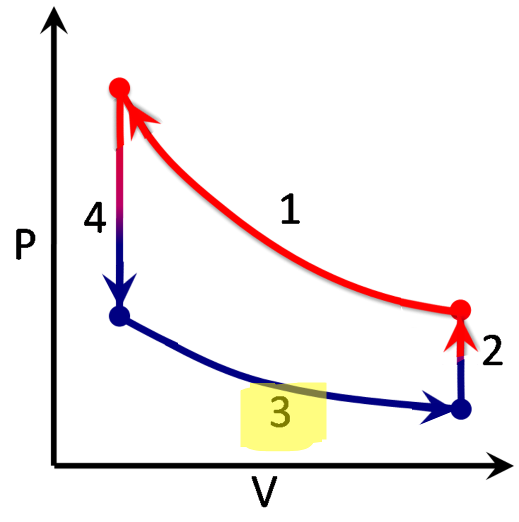
- The gas is now allowed to expand at constant temperature from 5 L back to 20 L.
- Does heat flow in or out of the gas?
- What is Q for this process?

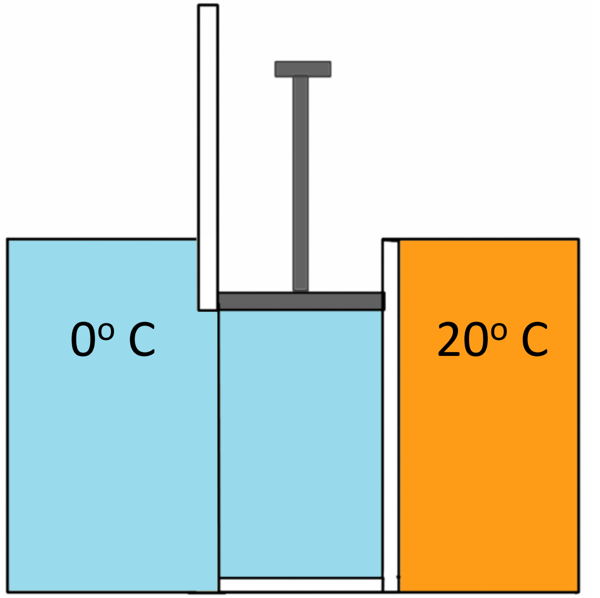
$$Q = \Delta U + W$$

$$\Delta U \rightarrow nC_v\Delta T \qquad W \rightarrow nRT\ln\frac{V_f}{V_i}$$

$$V_f \rightarrow 20 \qquad V_i \rightarrow 5$$

$$= +3145\text{ J}$$





- What is the final pressure?