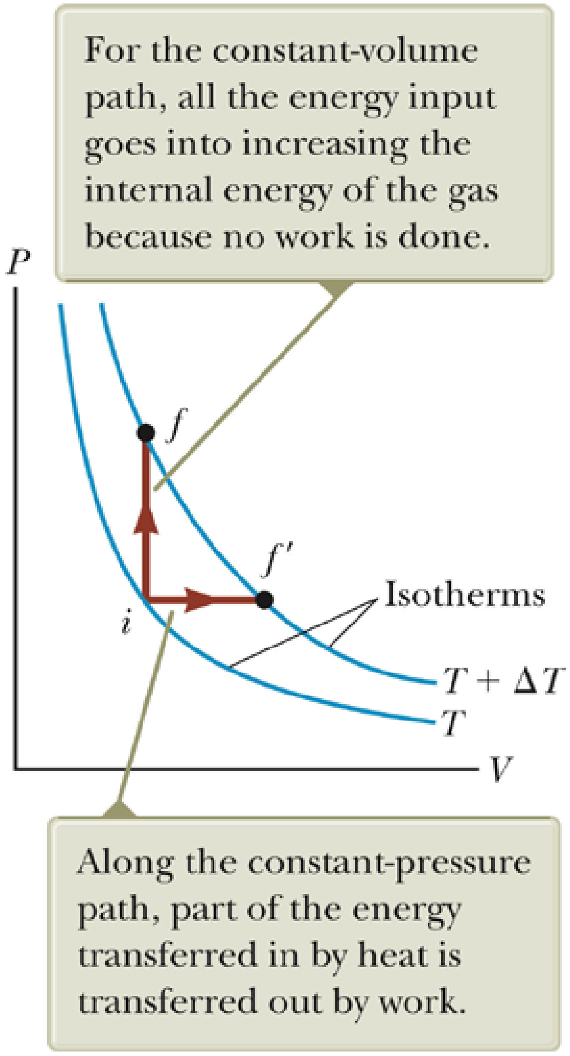
Thermal Physics

Lecture 6 – More P-V, Cycles, Molar specific heats

SpaceX:

https://youtu.be/ANv5UfZsvZQ

Last Lecture
Molar specific heats



At constant volume

$$Q = nC_V\Delta T \qquad C_V = \frac{f}{2}R$$

At constant pressure

$$Q = nC_P\Delta T \qquad C_P = \frac{f+2}{2}R$$

$$C_P - C_V = R$$

Adiabatic processes...

An adiabatic process is one in which no energy enters or leaves a system as heat.

$$\boxed{Q = 0}$$

- From the first law of thermodynamics, this means the only way you can change the internal energy of a system in a adiabatic process is to do work.

$$\Delta E_{int} = W$$

Last Lecture

Adiabatic processes are ones in which no heat enters or leaves a system: *insulated*, or *fast*.

$$Q = 0$$

$$\Delta E_{int} = W$$

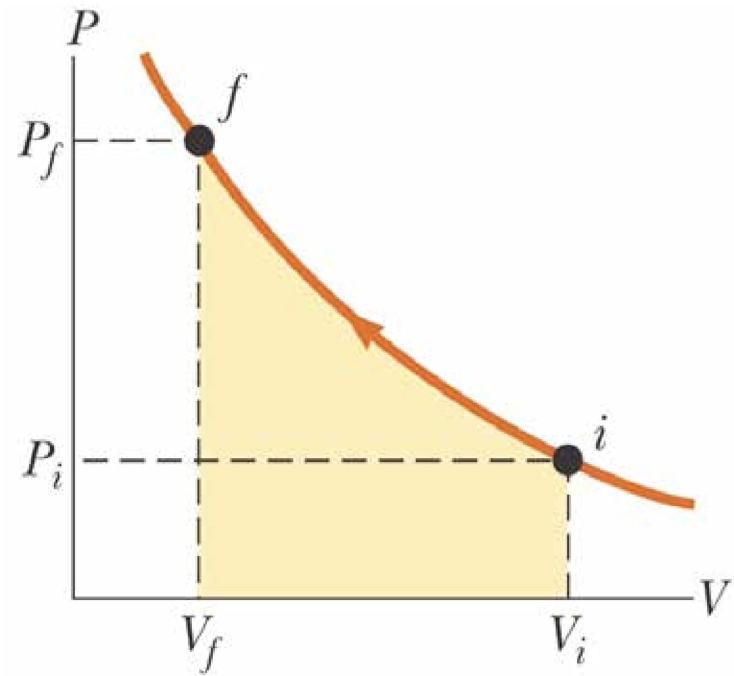
$$PV^{\gamma} = \text{constant}$$

Named processes...

- There are literally an infinite number of possible paths connecting i and f on a PV-diagram...

A few of these paths even have names:

- Isothermal
- Isobaric
- Isovolumetric
- (Adiabatic, $Q = 0$)



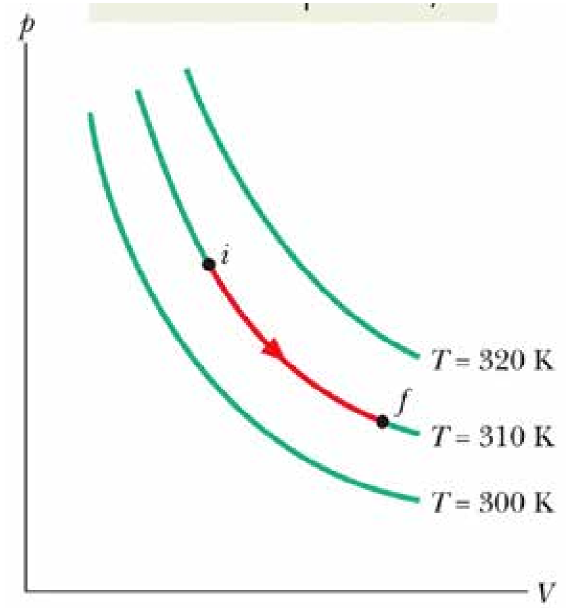
Named processes: Isothermal...

An isothermal process is one carried out at **constant temperature**.

- For an isothermal process:

$$PV = \text{constant}$$

$$(PV = nRT)$$



$$\Delta E_{int} = 0$$

- Any energy that enters the system by heat must leave the system by work.

$$\Delta E_{int} = Q + W$$

Named processes: Isobaric...

A process carried out at **constant pressure**.

- Work is generally nonzero because volume changes:

$$\frac{T}{V} = \text{constant} \qquad (PV = nRT)$$

- Heat is also generally nonzero because temperature changes as work is done.

$$Q = nc_P\Delta T \qquad \Delta E_{int} = Q + W$$

Molar specific heat at constant pressure

Named processes>Isovolumetric...

A process that takes place at a **constant volume** is called an isovolumetric process.

- No work is done because the volume does not change.

$$W = 0$$

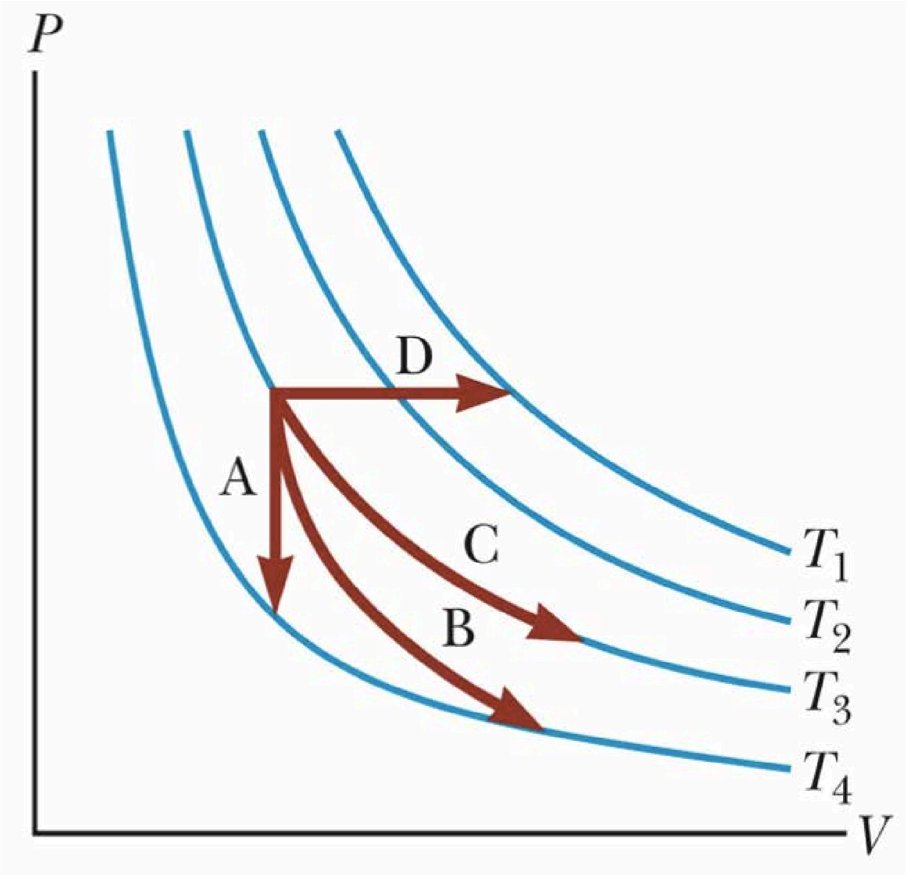
$$\Delta E_{int} = Q$$

Molar specific heat at constant volume

$$Q = nC_V \Delta T$$

Question...

- Name these 4 processes.



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Question

An ideal gas initially at 300 K undergoes an isobaric expansion at 2.50 kPa. If the volume increases from 1.00 m^3 to 3.00 m^3 and 12.5 kJ is transferred to the gas by heat, what are

a) the change in internal energy

b) its final temperature

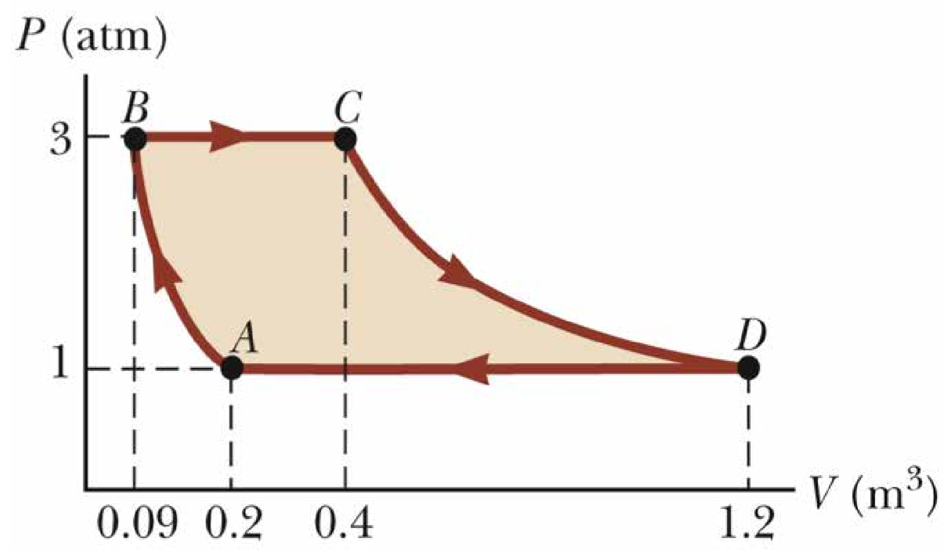
Cyclic processes

Process that starts and ends **in the same state** (same P, V and T) of the system. $(PV = nRT)$

- Same initial and final internal energy.

  $\Delta E_{int} = 0$

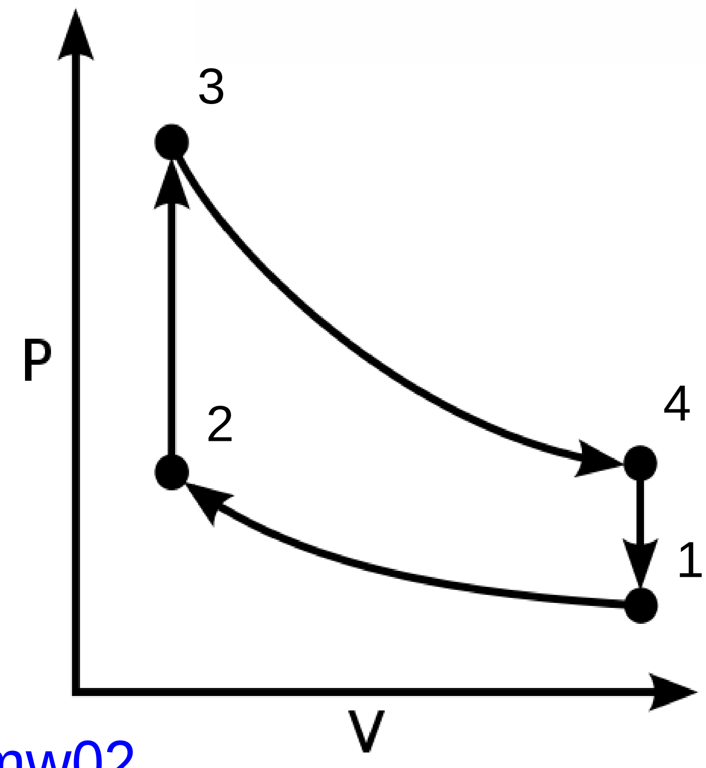
  $\Rightarrow Q = -W$



Question...

Consider the cyclic process
$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1$ shown.
What is the net work done **on** the gas?

1. Negative
2. Positive
3. None



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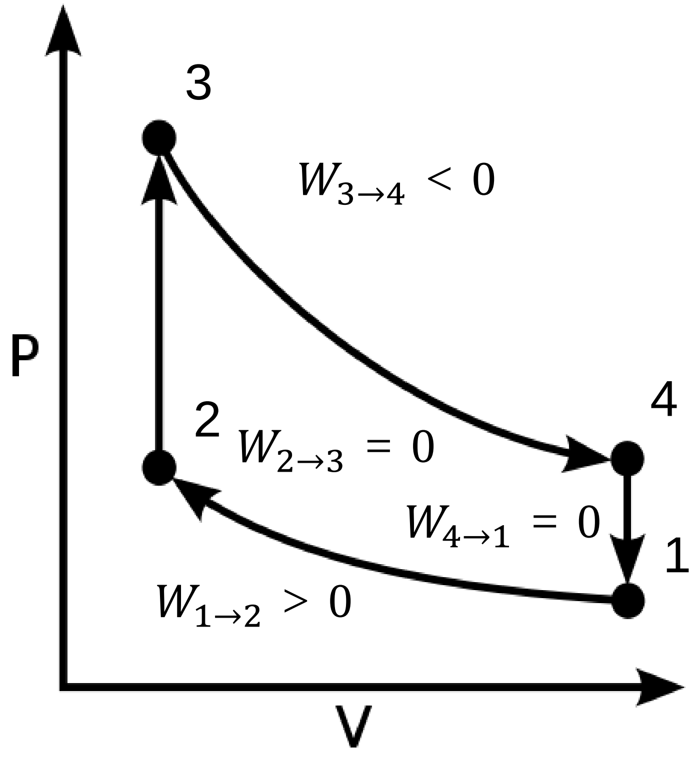
Question...

- Consider the cyclic process $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1$ shown below. What is the net work done **on** the gas?

1. Negative
2. Positive
3. None

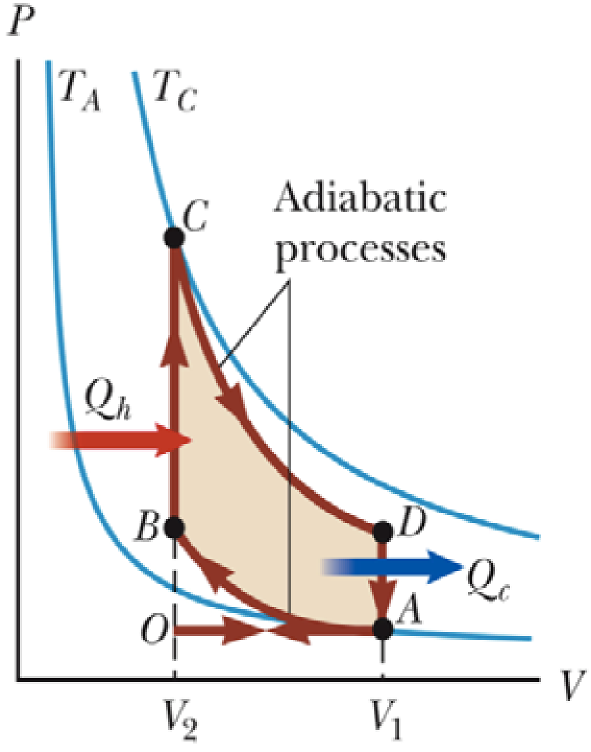
$|W_{3\rightarrow4}| > |W_{1\rightarrow2}|$

Work is done **by** the gas in this cycle!



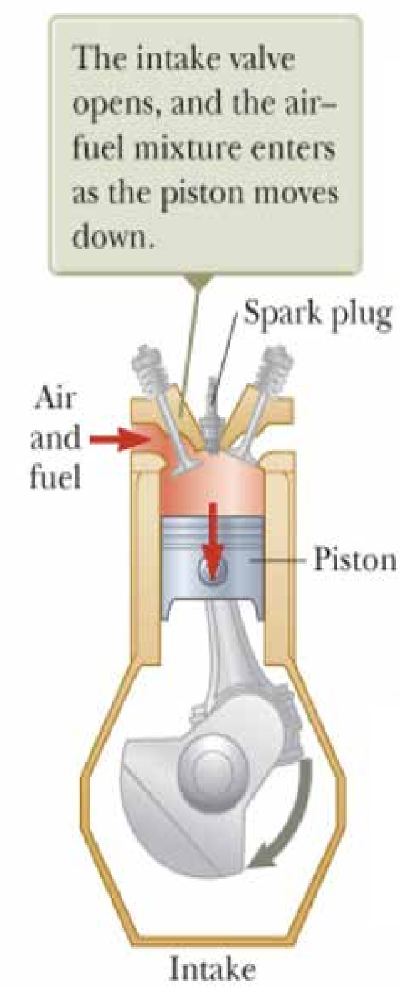
Cyclic processes>Heat engines...

- Cyclic processes form the basis of heat engines, which convert heat to work.



Example: gasoline engine

- Intake stroke: O → A



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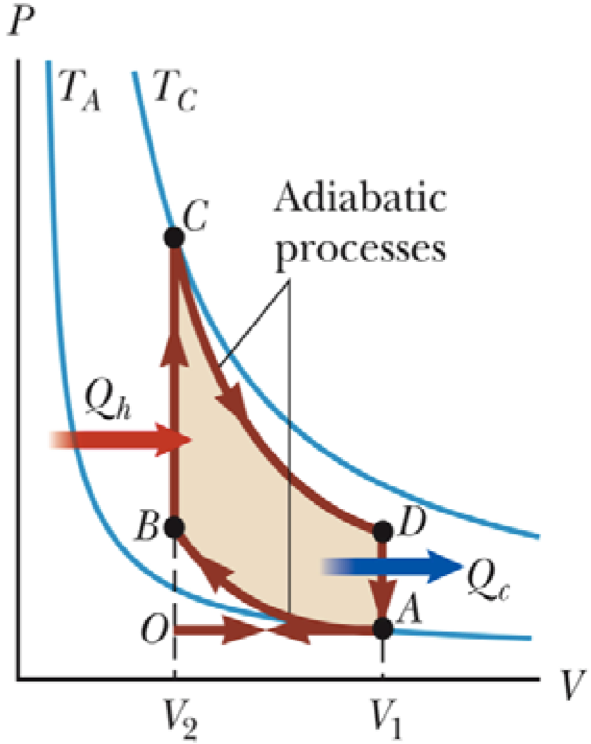
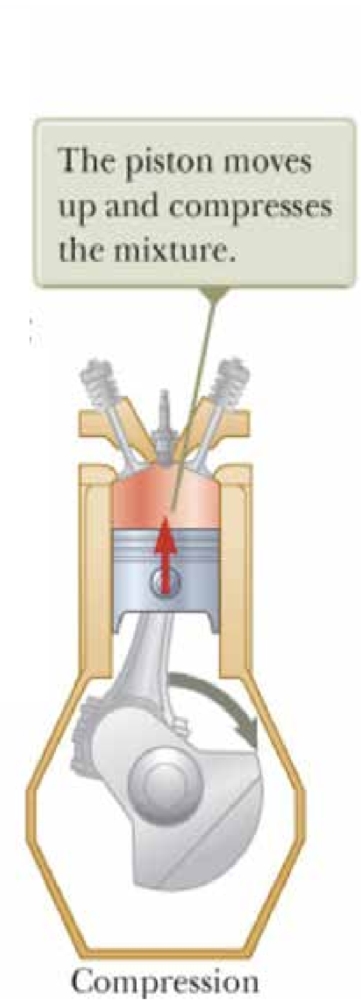


Example: gasoline engine

- Intake stroke: O → A
- Compression stroke A → B



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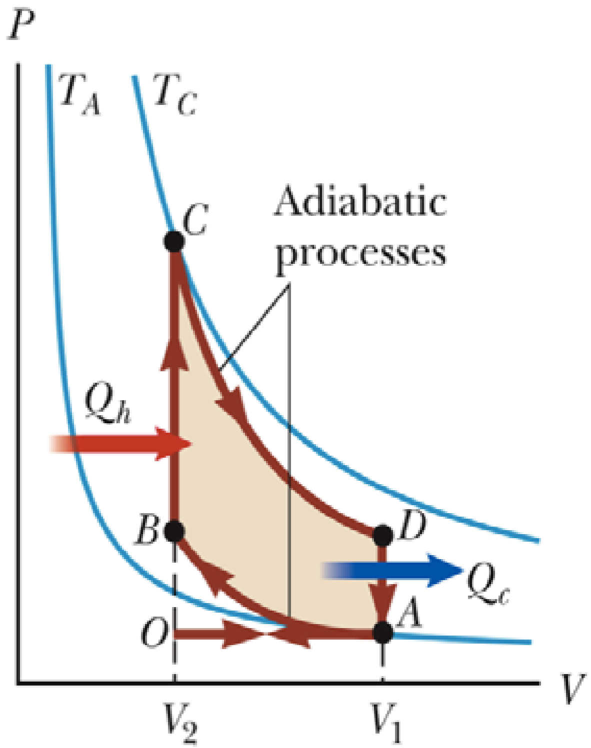
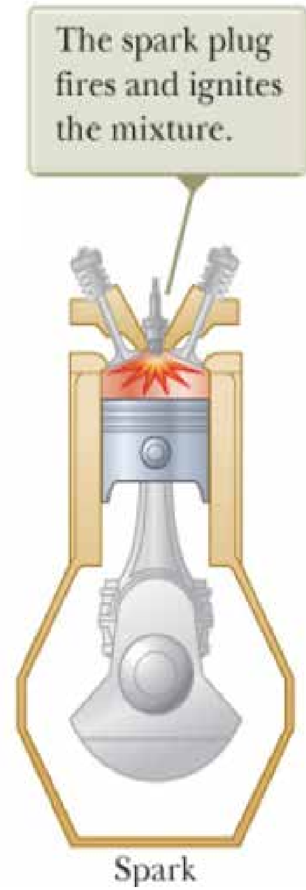


Example: gasoline engine

- Intake stroke: O → A
- Compression stroke A → B
- Spark B → C



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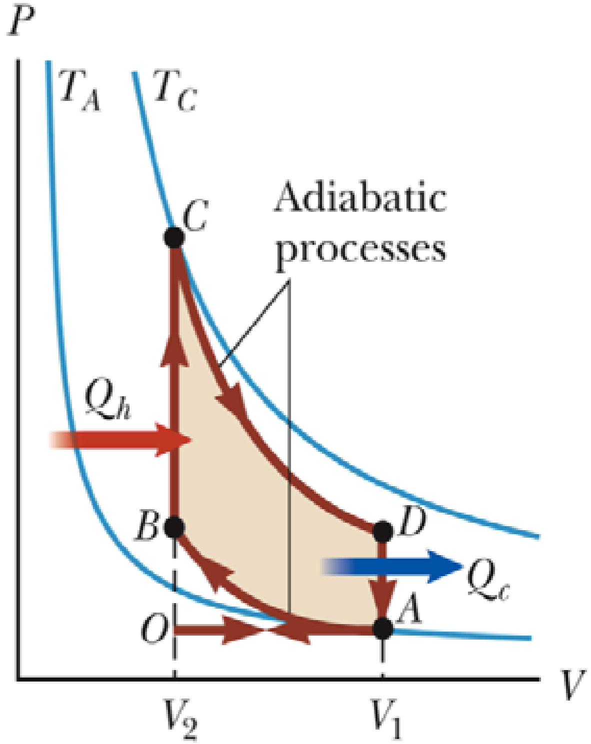
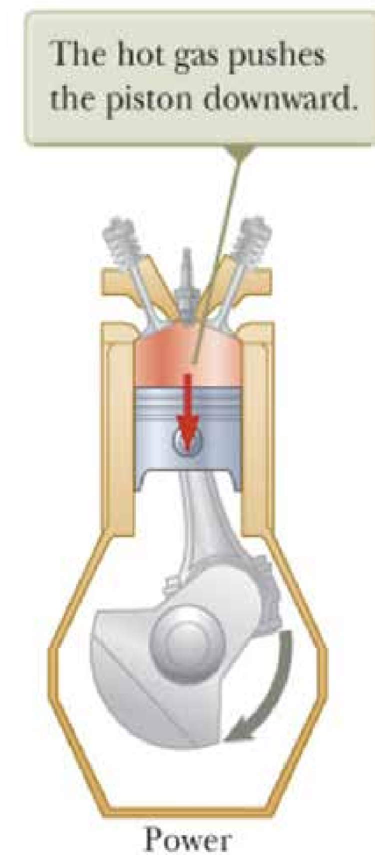


Example: gasoline engine

- Intake stroke: O → A
- Compression stroke A → B
- Spark B → C
- Power stroke C → D



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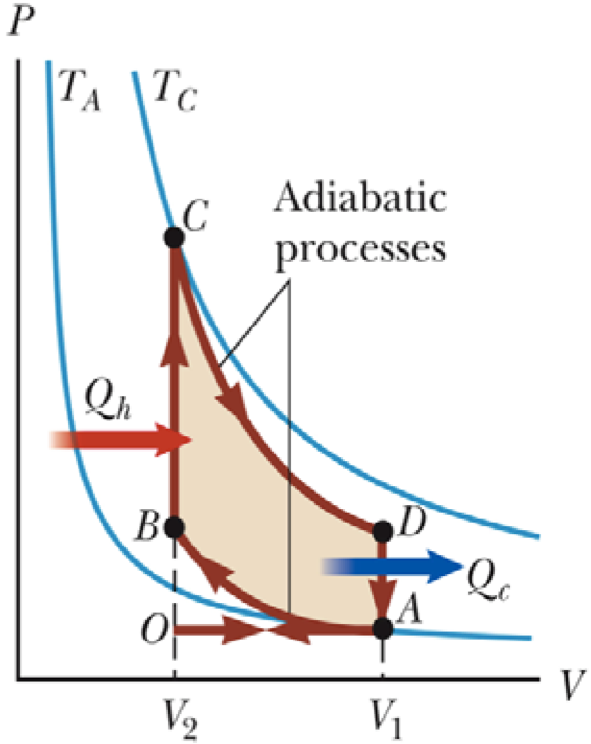
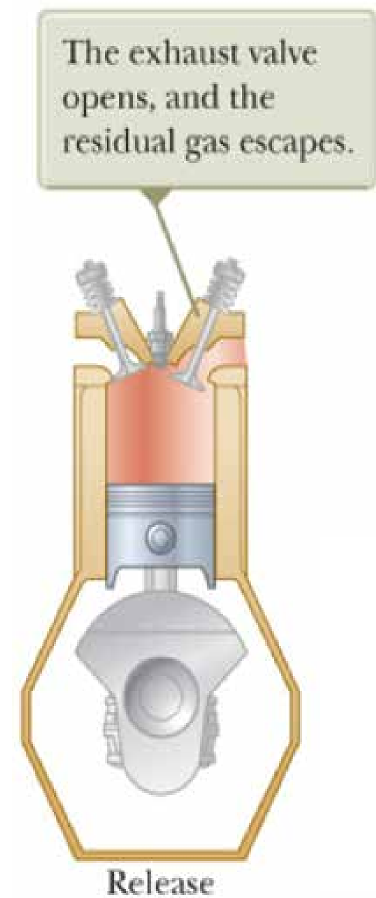


Example: gasoline engine

- Intake stroke: O → A
- Compression stroke A → B
- Spark B → C
- Power stroke C → D
- Pressure release D → A



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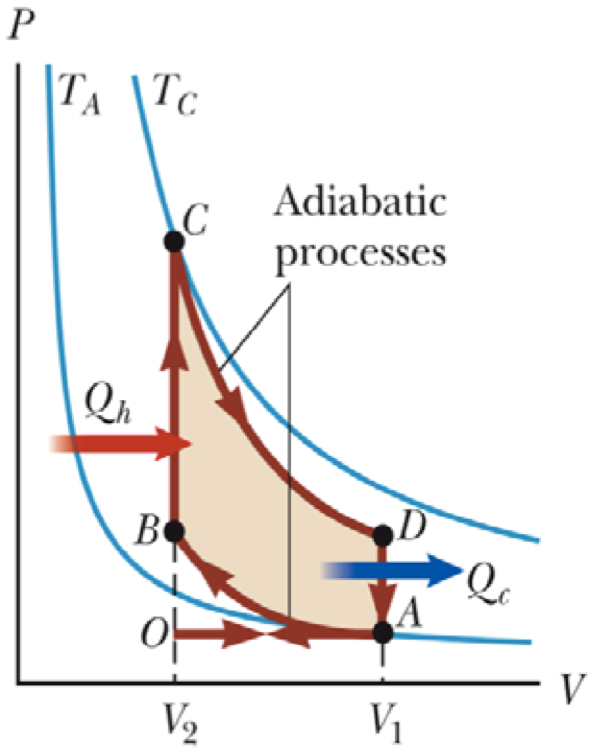
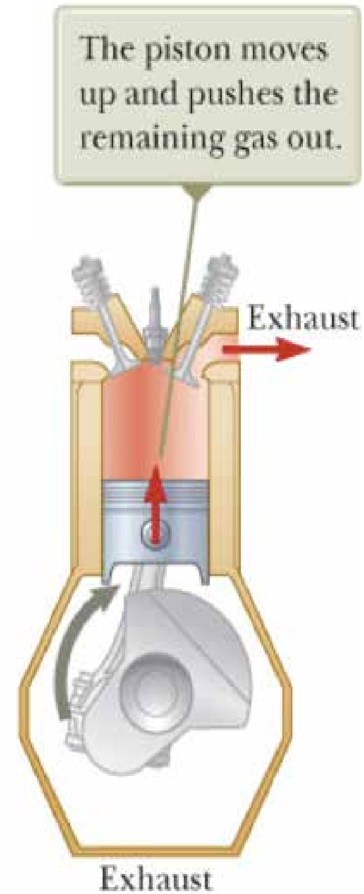
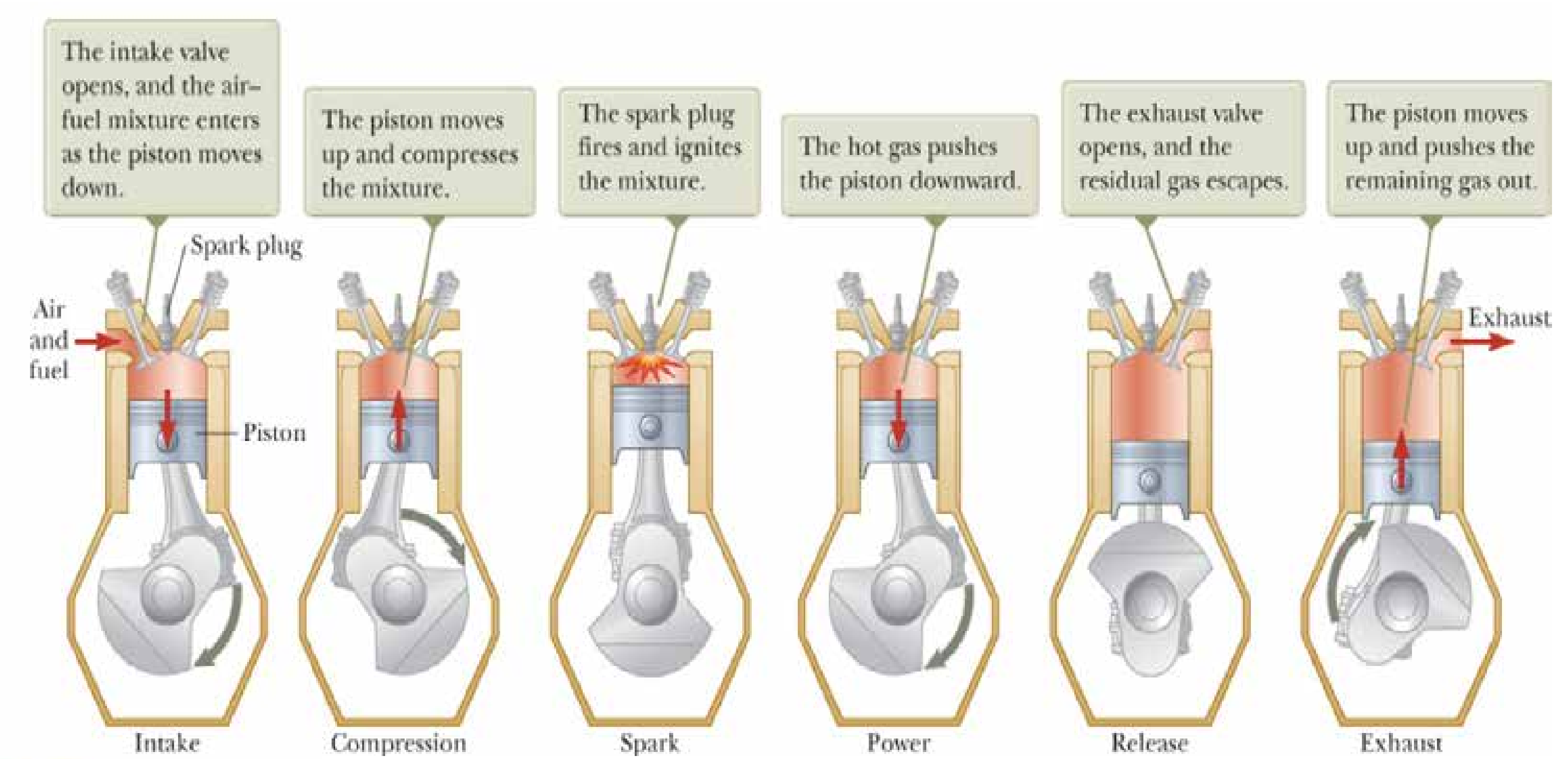


Example: gasoline engine

- Intake stroke: O → A
- Compression stroke A → B
- Spark B → C
- Power stroke C → D
- Pressure release D → A
- Exhaust stroke A → O



Cyclic processes>Heat engines...



Stirling engine: https://youtu.be/saCdvAp5cow?t=7s

Question

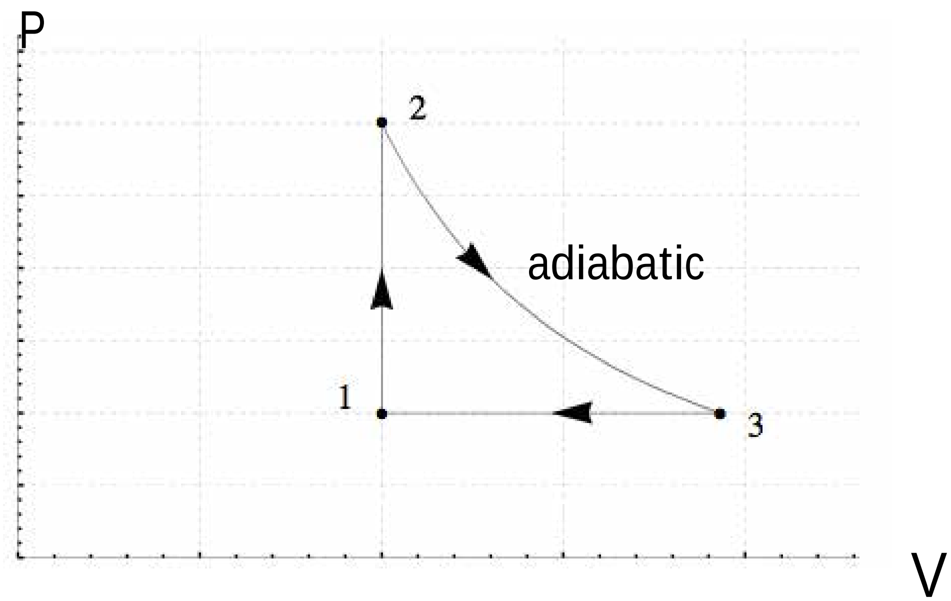
The figure below shows a cycle undergone by 1.00 mol of an ideal monatomic gas. The temperatures are T_1 = 300 K, T_2 = 600 K, and T_3 = 455 K.

For 1 è 2, what are

a) Heat, Q

b) Change in internal energy

c) the work done, W?



Question cont.

For 2 è 3 what are

d) Q

e) change in internal energy

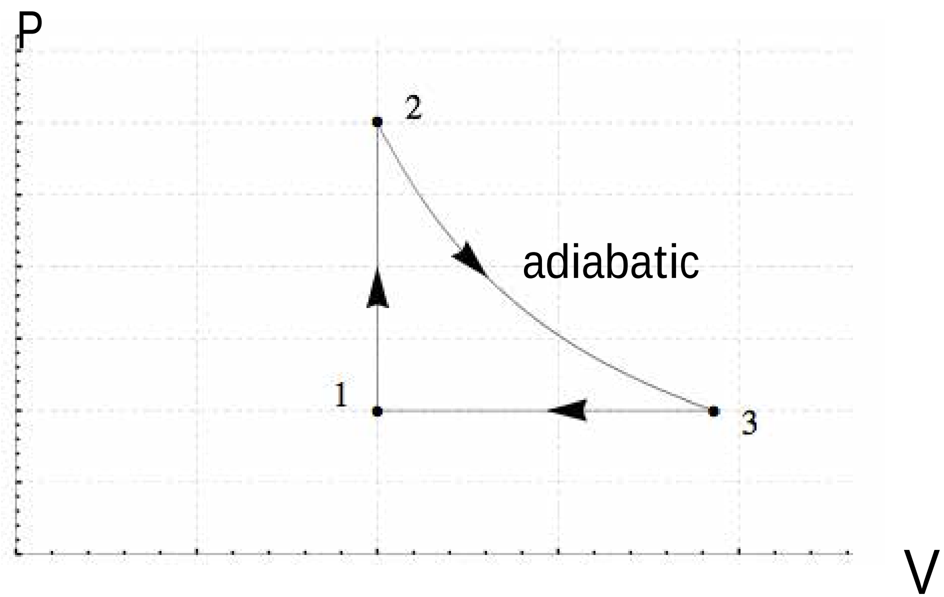
f) W?

For 3 è 1 what are

g) Q

h) change in internal energy

i) W?



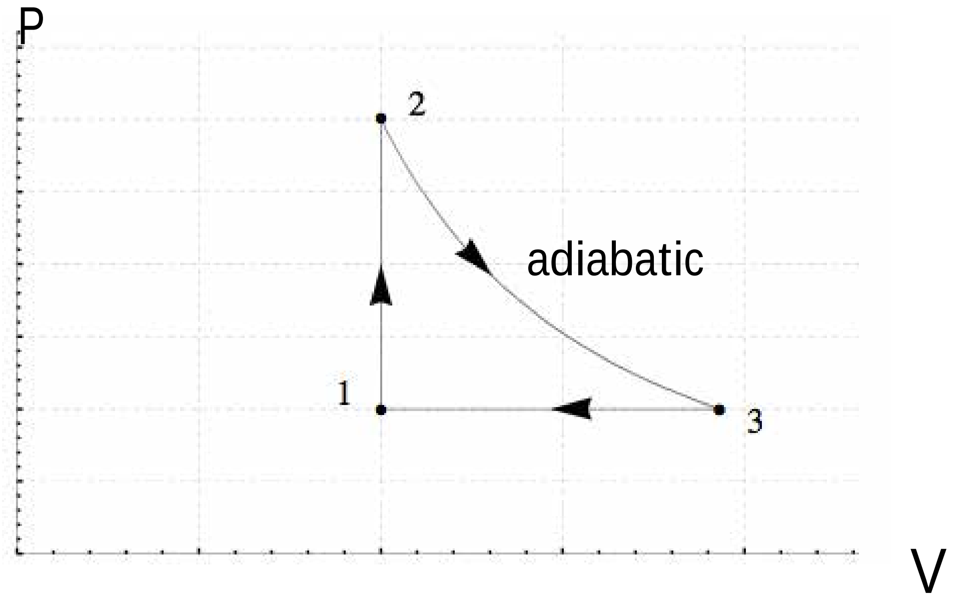
Question cont.

For the full cycle what are

- j) Q
- k) change in internal energy
- l) W?

The initial pressure at point 1 is 1.00 atm. What are

- m) volume at point 2
- n) pressure at point 2
- o) volume at point 3
- p) pressure at point 3



Perpetual motion machines

$$\Delta E_{int} = Q + W$$

Energy conservation: “you can’t win”

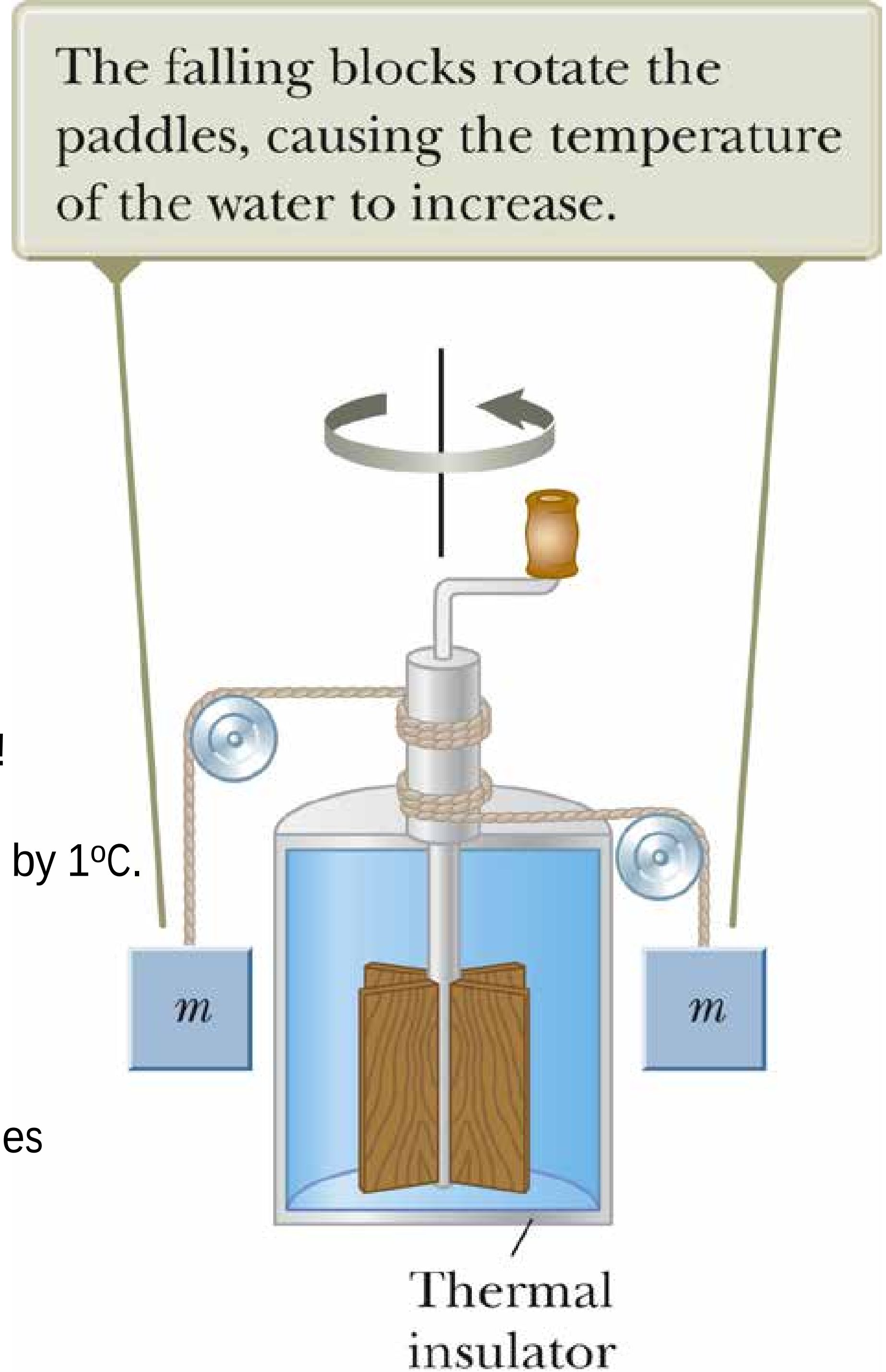
Joule's experiment for determining
the mechanical equivalent of heat.

You can work out the gravitational potential energy transferred to the water.

This is how the calorie is determined!
How much energy required to
raise temperature of 1 gram of water by 1^oC.

1 calorie = 4.186 J

Warning!
Food calorie = "Calorie" = 1000 calories
= 1 kcal = 4.186 kJ



Heat Capacity

- The **heat capacity**, C, of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by 1^{o}C
- If energy *Q* produces a change of temperature of D*T*, then

$$Q = C\ \mathrm{D}T$$

Specific Heat

- **Specific Heat**, c, is the heat capacity per unit mass; i.e. $c=C/m$
- If energy Q transfers to a sample of a substance of mass m and the temperature changes by DT, then the specific heat is

$$c \equiv \frac{Q}{m\,\Delta T}$$

Specific Heat, c

This relates the heat to the change in temperature of a substance:

$$Q = mc\Delta T$$

'c' is called the "Specific Heat" of a substance. It is a measure of how <u>insensitive</u> a substance is to the addition of energy.

A better term would be "specific energy transfer" (recall definition of heat).

Specific Heat, c

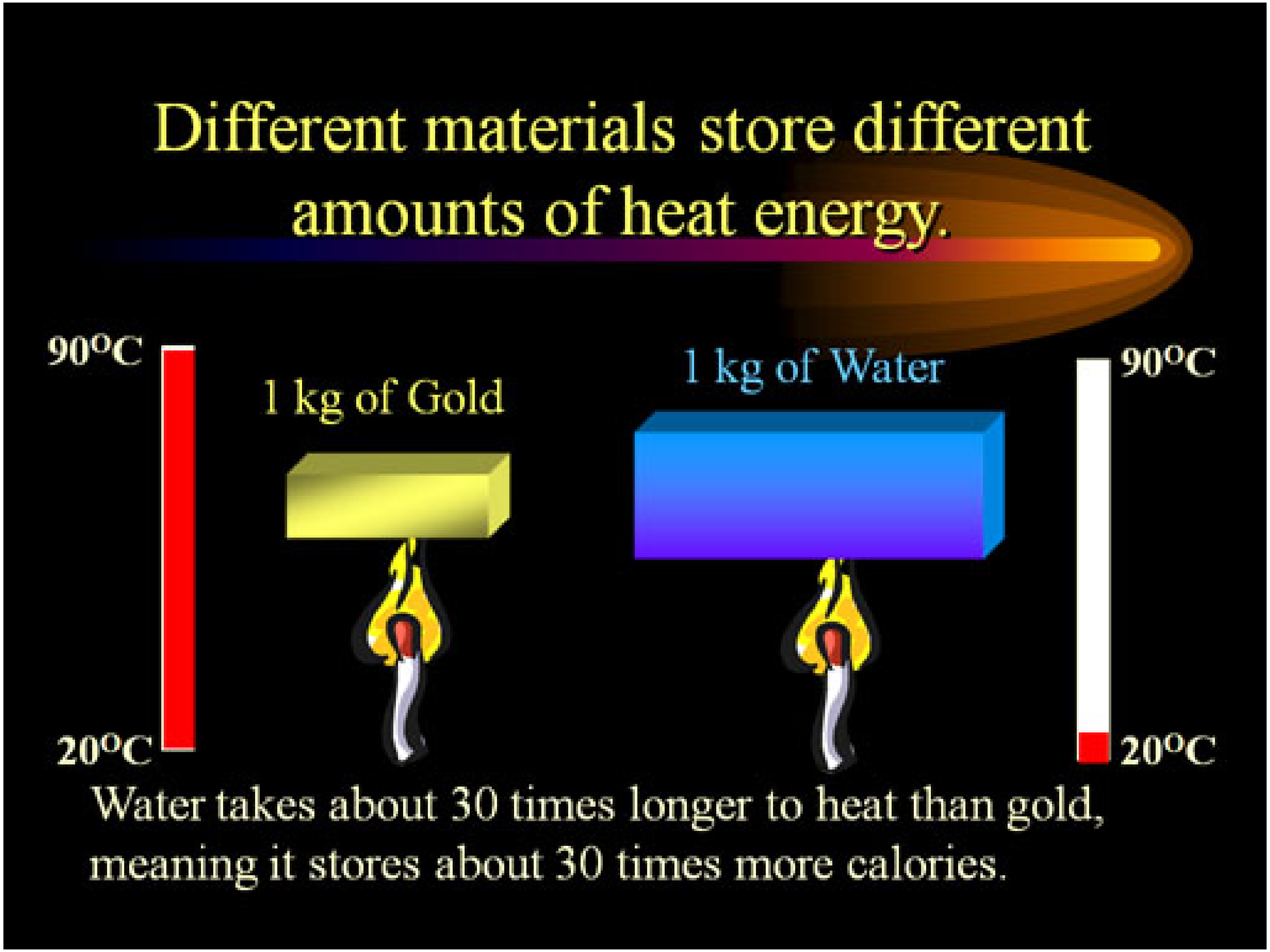


TABLE 20.1 *Specific Heats of Some Substances at 25°C and Atmospheric Pressure*

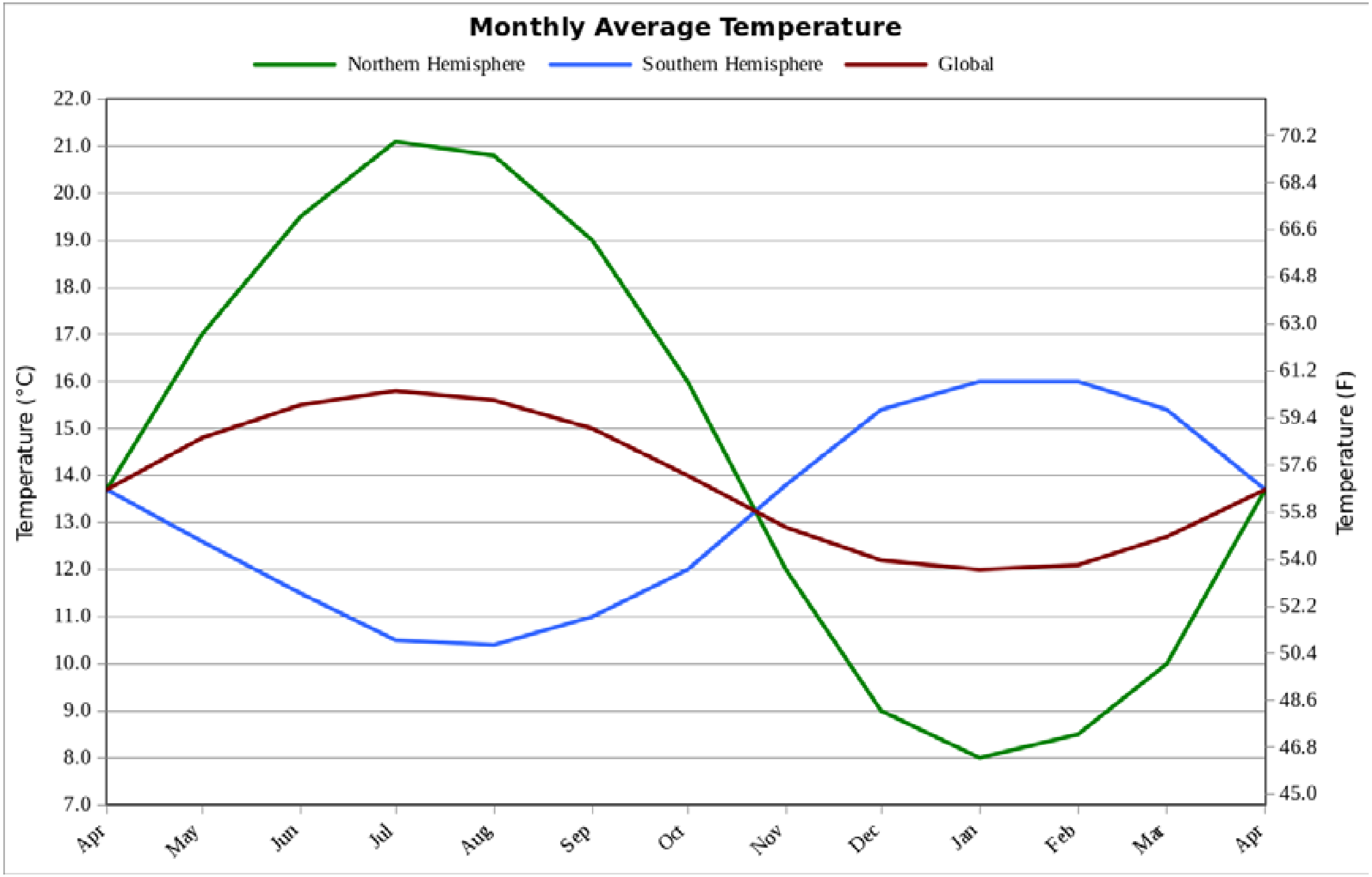
Substance	Specific Heat (J/kg · °C)	Substance	Specific Heat (J/kg · °C)
Elemental solids		*Other solids*	
Aluminum	900	Brass	380
Beryllium	1 830	Glass	837
Cadmium	230	Ice (−5°C)	2 090
Copper	387	Marble	860
Germanium	322	Wood	1 700
Gold	129	*Liquids*	
Iron	448	Alcohol (ethyl)	2 400
Lead	128	Mercury	140
Silicon	703	Water (15°C)	4 186
Silver	234	*Gas*	
		Steam (100°C)	2 010

Note: To convert values to units of cal/g · °C, divide by 4 186.

In your textbook this is table 19.2 on page 556

Sign Conventions

- If the temperature increases:
  - *Q* and D*T* are positive
  - Energy transfers **into** the system
- If the temperature decreases:
  - *Q* and D*T* are negative
  - Energy transfers **out** of the system



Why does the Northern Hemisphere vary more over a year?
(hint: think about specific heat of land vs. water)
(hint2: Land can be grossly approximated as being composed of silicon in Table 19.2)

Imagine you have 1 kg each of iron, glass, and water, all at 10 ° C.

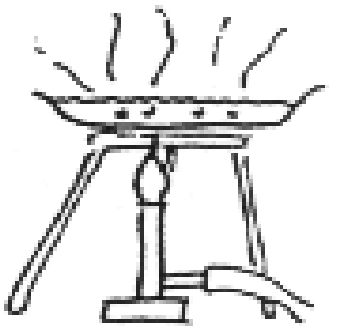
Rank the samples from lowest to highest temperature after 100J of energy is added to each sample.

1. Iron
2. Glass
3. Water

https://goo.gl/forms/KgnnQhSZWGI71mw02

Demo Unit Hb7: thermal conductivity

- Boiling water in a paper plate
- What do you expect to happen?



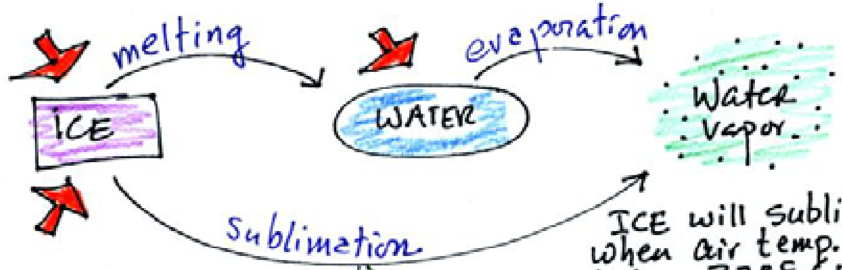
Phase Changes

Phase Changes

- A **phase change** is when a substance changes from one form to another
  - Two common phase changes are
    - Solid to liquid (melting)
    - Liquid to gas (boiling)
- During a phase change, there is no change in temperature of the substance
- We describe the amount of energy required to effect the change by the "Latent Heat"

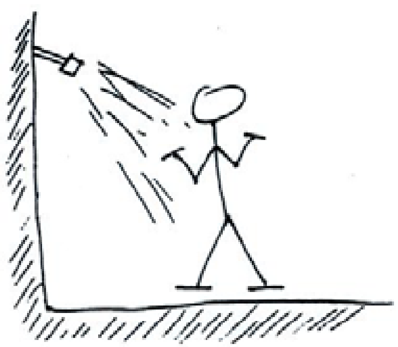
ENERGY TRANSPORT in the FORM of LATENT HEAT

consciously ADD ENERGY (place material in a pan, put on a hot stove)
(needed energy may be taken from surroundings)



ICE will sublimate when air temp. is below 32°F (0°C).

example: dry ICE (solid CO_2)



Phase changes sometimes occur "whether we want them to or not." They still require energy & take it from their surroundings.

Step out of a shower. Water evaporates. Needed energy is taken from your body — you feel cold.

Latent Heat, *L*

- Different substances react differently to the energy added or removed during a phase change due to their different molecular arrangements
- The amount of energy also depends on the mass of the sample
- If an amount of energy Q is required to change the phase of a sample of mass m, then $L = Q/m$

Latent Heat, cont

- The quantity *L* is called the **latent heat** of the material
  - Latent means “hidden”
  - The value of *L* depends on the substance as well as the actual phase change
- The energy required to change the phase is

$$Q = \pm \ \mathrm{D}mL$$

+ sign if going UP in phase (solid à liquid à gas)

- sign if going DOWN in phase (gas à liquid à solid)

Latent Heat, final

- The *latent heat of fusion* is used when the phase change is from solid to liquid
- The *latent heat of vaporisation* is used when the phase change is from liquid to gas
- The positive sign is used when the energy is transferred into the system
  - This will result in melting or boiling
- The negative sign is used when energy is transferred out of the system
  - This will result in freezing or condensation