

# Lecture 3

## Chapter 18: Temperature, heat and the first law of thermodynamics

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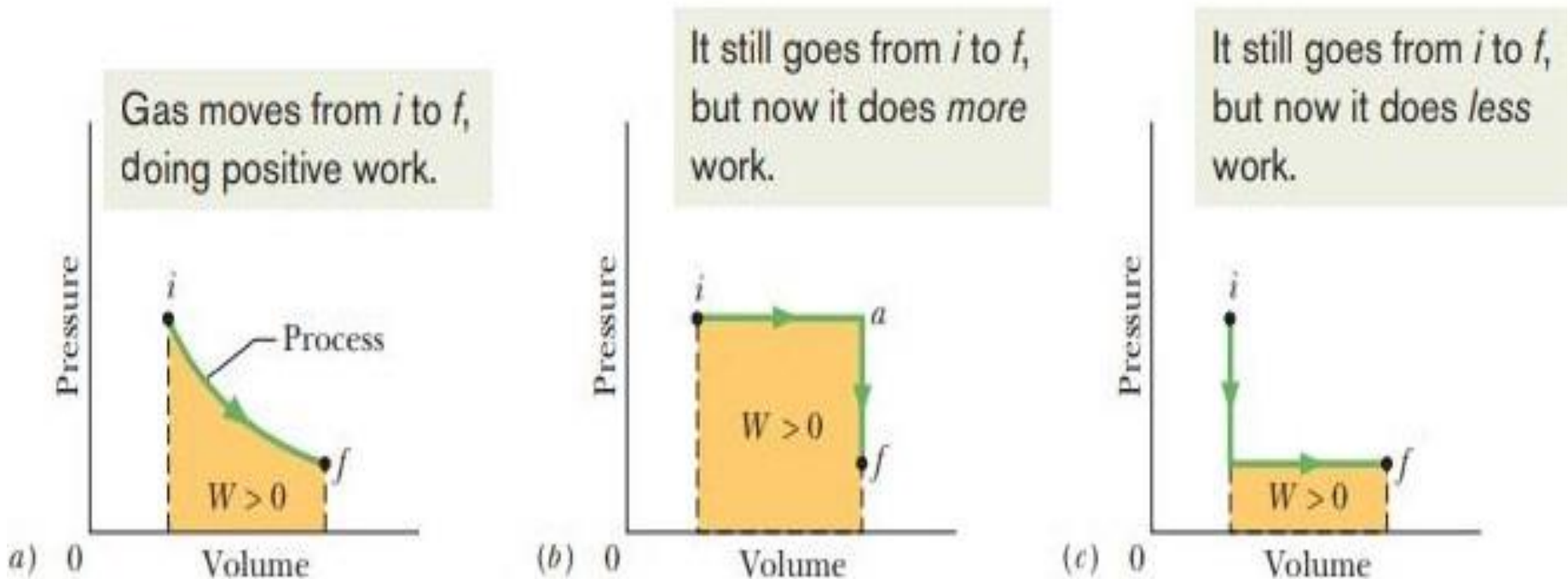
### Chapter 18: Temperature, heat and the first law of thermodynamics

#### 18.5: Path dependent work done in terms of p-V diagram:

Work done is always **area** under the p-V curve:

$$W = \int_{V_i}^{V_f} p \, dV = p(V_f - V_i) = p\Delta V$$

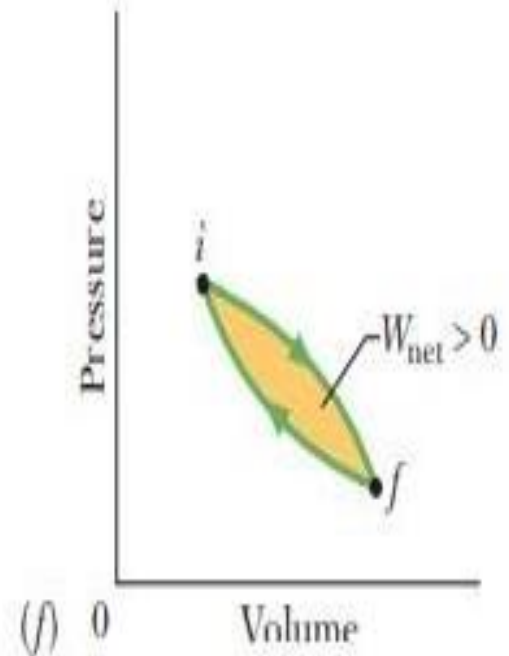
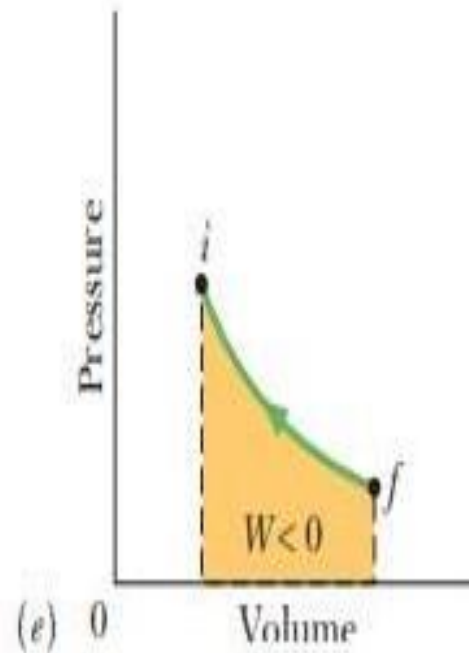
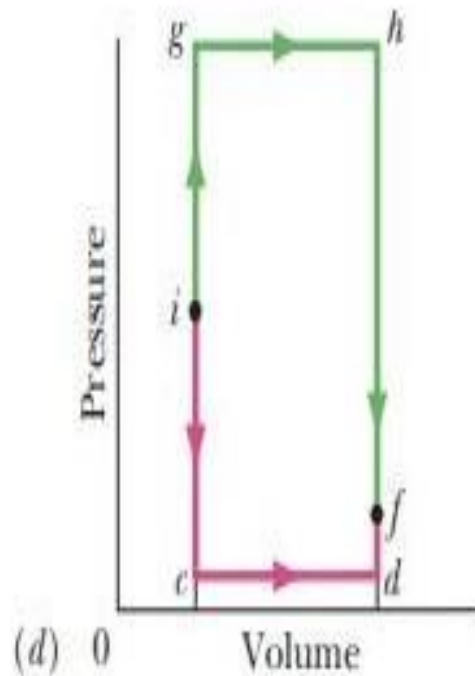
The amount of work depends on path.



We can control how much work it does.

Moving from  $f$  to  $i$ , it does negative work.

Cycling clockwise yields a positive net work.



## 18.5: The First Law of Thermodynamics

When a system changes from a given initial state to a given final state, both the work  $W$  and the heat  $Q$  depend on the **nature of the process** but the **quantity  $Q - W$  is the same for all processes**. It **depends** only on the **initial and final states** and **does not depend** at all on **how the system gets** from one to the other. All other combinations of  $Q$  and  $W$ , including  $Q$  alone,  $W$  alone,  $Q + W$ , and  $Q - 2W$ , are **path dependent**; only the **quantity  $Q - W$  is not**. The quantity  $Q - W$  must represent a **change in some intrinsic property** of the system. We call this property the **internal energy  $E_{int}$**  and we write

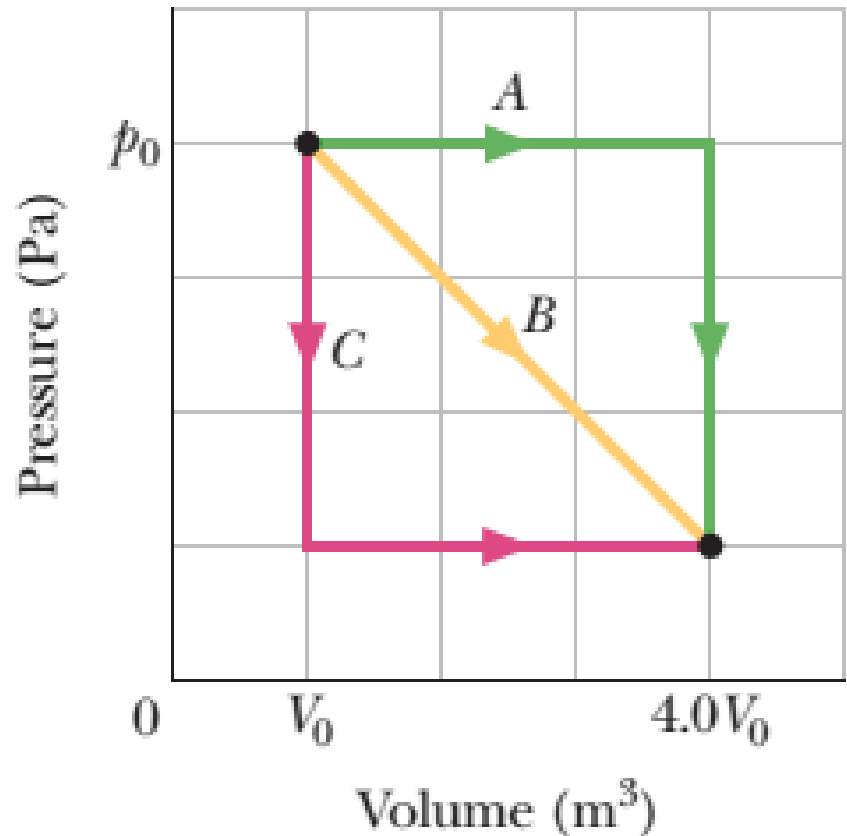
$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W$$

The equation known as the **first law of thermodynamics**.

If the thermodynamic system undergoes only a **differential change**, we can write the first law as

$$dE_{int} = dQ - dW$$

- 43. In Fig., a gas sample expands from  $V_0$  to  $4.0V_0$  while its pressure decreases from  $p_0$  to  $p_0/4.0$ . If  $V_0 = 1.0 \text{ m}^3$  and  $p_0 = 40 \text{ Pa}$ , how much work is done by the gas if its pressure changes with volume via (a) path A, (b) path B, and (c) path C?



### Solution of 43

The volume increases through the three paths , so the work done by the gas is always positive.

$$W = \int dW = \int_{V_i}^{V_f} p dV = \text{Area under the curve of } p\text{-}V$$

$$(a) W_A = W_{A1} + W_{A2}$$

$$W_{A1} = 40 (4-1) = +120 \text{ J}$$

(constant pressure)

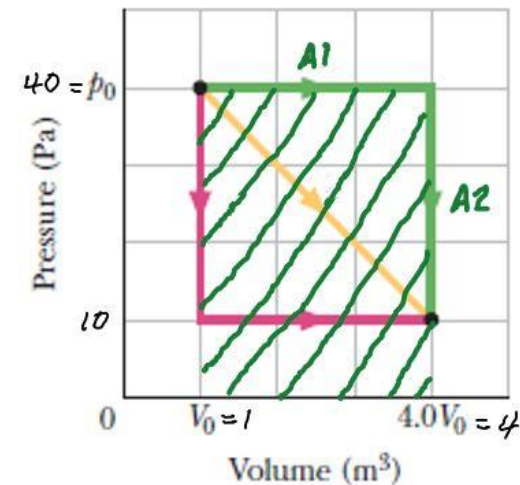
$$W_{A2} = 0 \text{ (constant volume)}$$

$$W_A = 120 + 0 = +120 \text{ J}$$

or

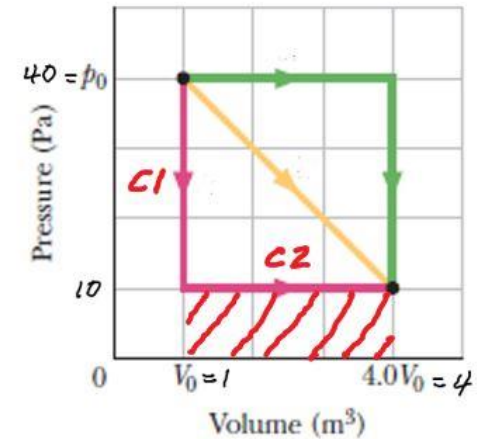
$$[W = p\Delta V = p(V_f - V_i) = (40-0)(4-1)]$$

$$W = 40(3) = +120 \text{ J}]$$



(b) The work done by the gas is the area under the curve (yellow line)

$$\begin{aligned} W_B &= \frac{1}{2} \times (4 - 1)(40 - 10) + (4 - 1)(10 - 0) \\ &= (45 + 30) \text{ J} \\ &= +75 \text{ J} \end{aligned}$$

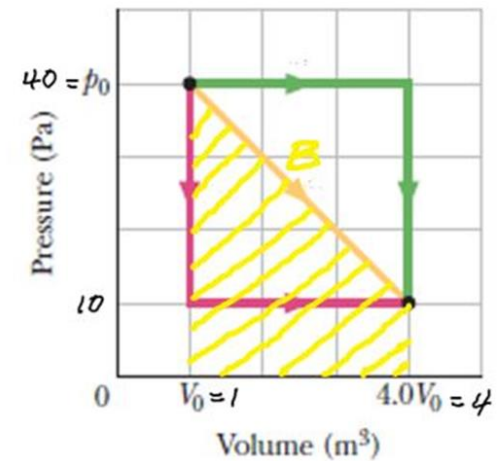


$$(c) W_C = W_{C1} + W_{C2}$$

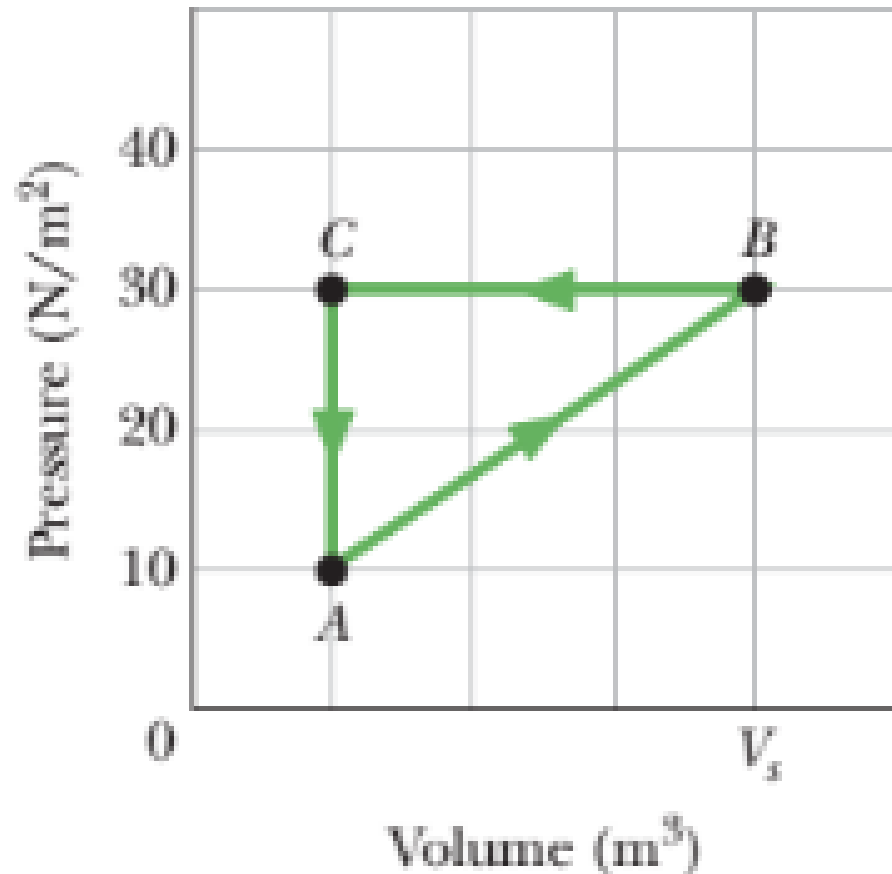
$$W_{C1} = 0 \text{ (constant volume)}$$

$$W_{C2} = (4 - 1)(10 - 0) = 30 \text{ J}$$

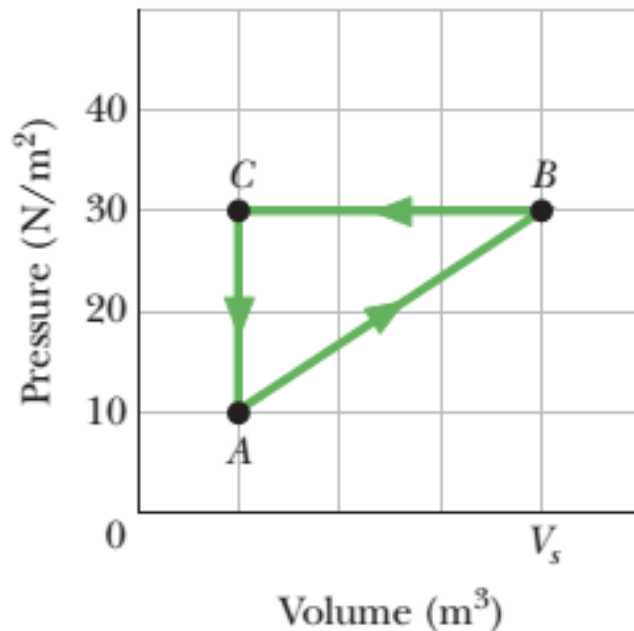
$$W_C = 0 + 30 = +30 \text{ J}$$



- 45. A gas within a closed chamber undergoes the cycle shown in the  $p$ - $V$  diagram of Fig. The horizontal scale is set by  $V_s = 4.0 \text{ m}^3$ . Calculate the net energy added to the system as heat during one complete cycle.







Solution:

Since for a closed cycle,  $\Delta E_{\text{int}} = E_f - E_i = 0$

1<sup>st</sup> law of thermodynamics,  $\Delta E_{\text{int}} = Q - W$

$$0 = Q - W$$

$$Q = W$$

The work done in a complete cycle is given by the area inside the loop (triangle)

$$W_{\text{net}} = \frac{1}{2} \times (4-1) (30-10) = 30 \text{ J}$$

Area under the curve B to C ( compression)  
Is greater than the area under the curve A to B (expansion). So the net work done is negative.

$$W_{\text{net}} = - 30 \text{ J}$$

$$[\text{or } W_{\text{net}} = \frac{1}{2} \times (V_f - V_i) (30-10) = \frac{1}{2} \times (1-4) (30-10) = - 30 \text{ J}]$$

$$Q = W = - 30 \text{ J}$$

The gas (system) loses heat.

Which  
path may  
do more  
work??

