SNS COLLEGE OF TECHNOLOGY
AN AUTONOMOUS INSTITUTION

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DEPARTMENT OF AGRICULTURAL ENGINEERING

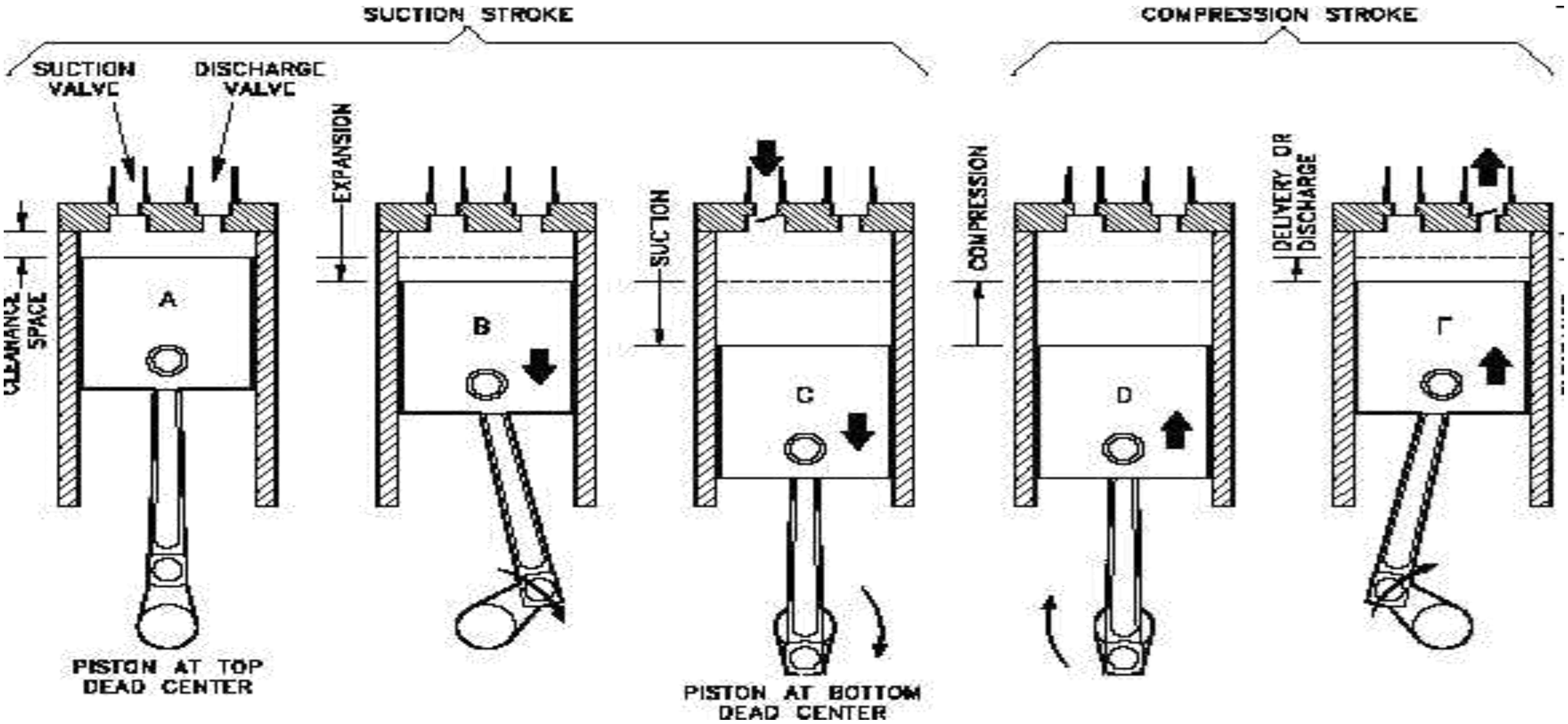
COURSE CODE & NAME: 19AGT301 & HEAT POWER ENGINEERING

III YEAR / V SEMESTER

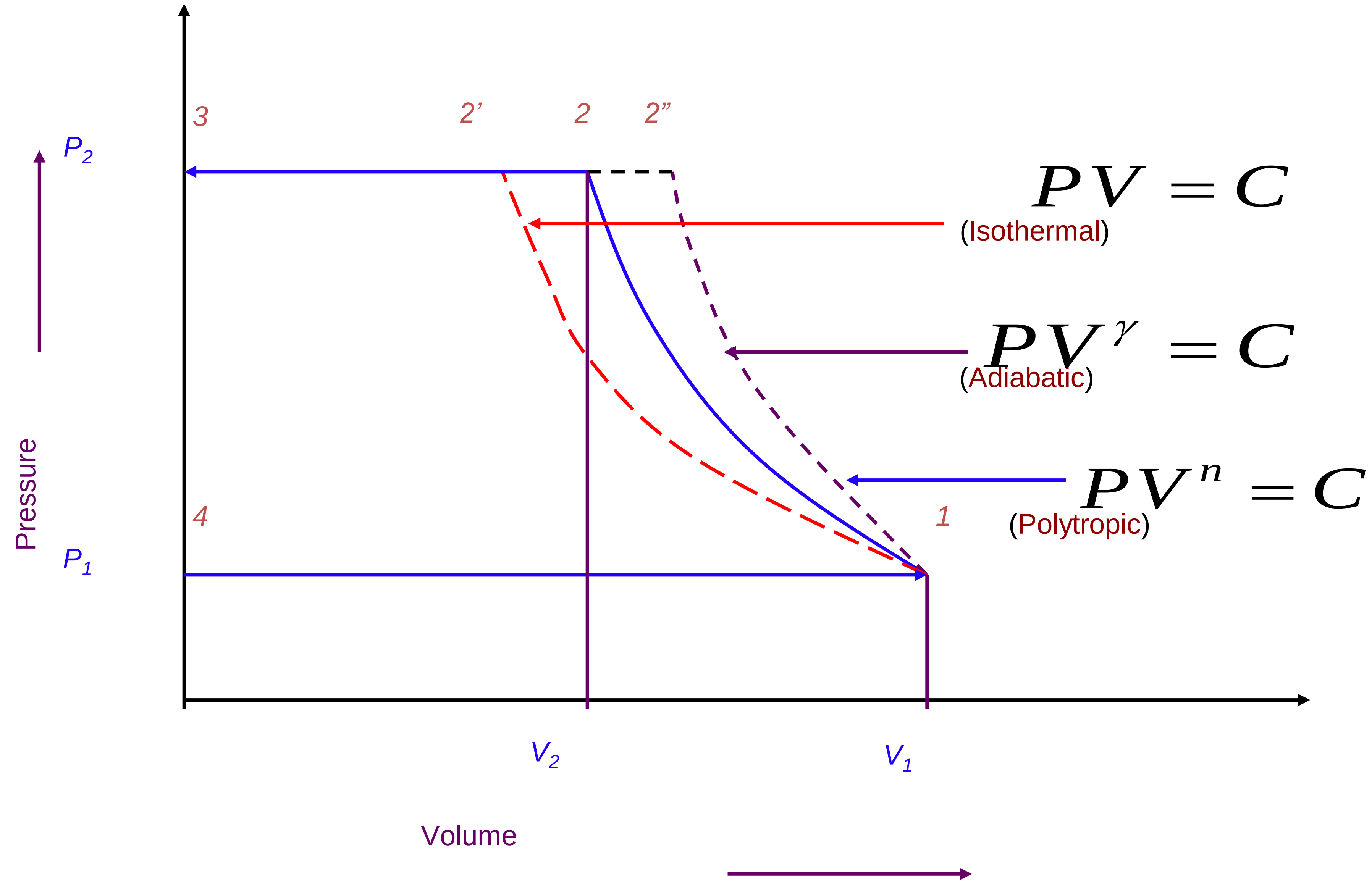
UNIT : IV IC ENGINE PERFORMANCE AND AIR COMPRESSORS

TOPIC 7 :Air Compressors

Reciprocating Compressor - Working



Reciprocating Compressor – Equation for Work



Operations : 4 – 1 : Volume V_1 of air aspirated into Compressor, at P_1 and T_1.

1 – 2 : Air compressed according to $PV^n = Const.$ from P_1 to P_2.

⟶ Temp increase from T_1 to T_2.

2 – 3 : Compressed air at P_2 and V_2 with temperature T_2 is delivered.

Reciprocating Compressor – Equation for Work

During Compression, due to the excess temperature above surrounding, the air will exchange the heat to the surrounding.

$\Longrightarrow$ Compression Index, *n* is always less than γ, the adiabatic index.

As Compressor is a work consuming device, every effort is desired to reduce the work.

Work done = Area under *P-V* curve

$\Longrightarrow$ 1 – 2” : Adiabatic Compression = Max. Work.

$\Longrightarrow$ 1 – 2 : Polytropic Compression

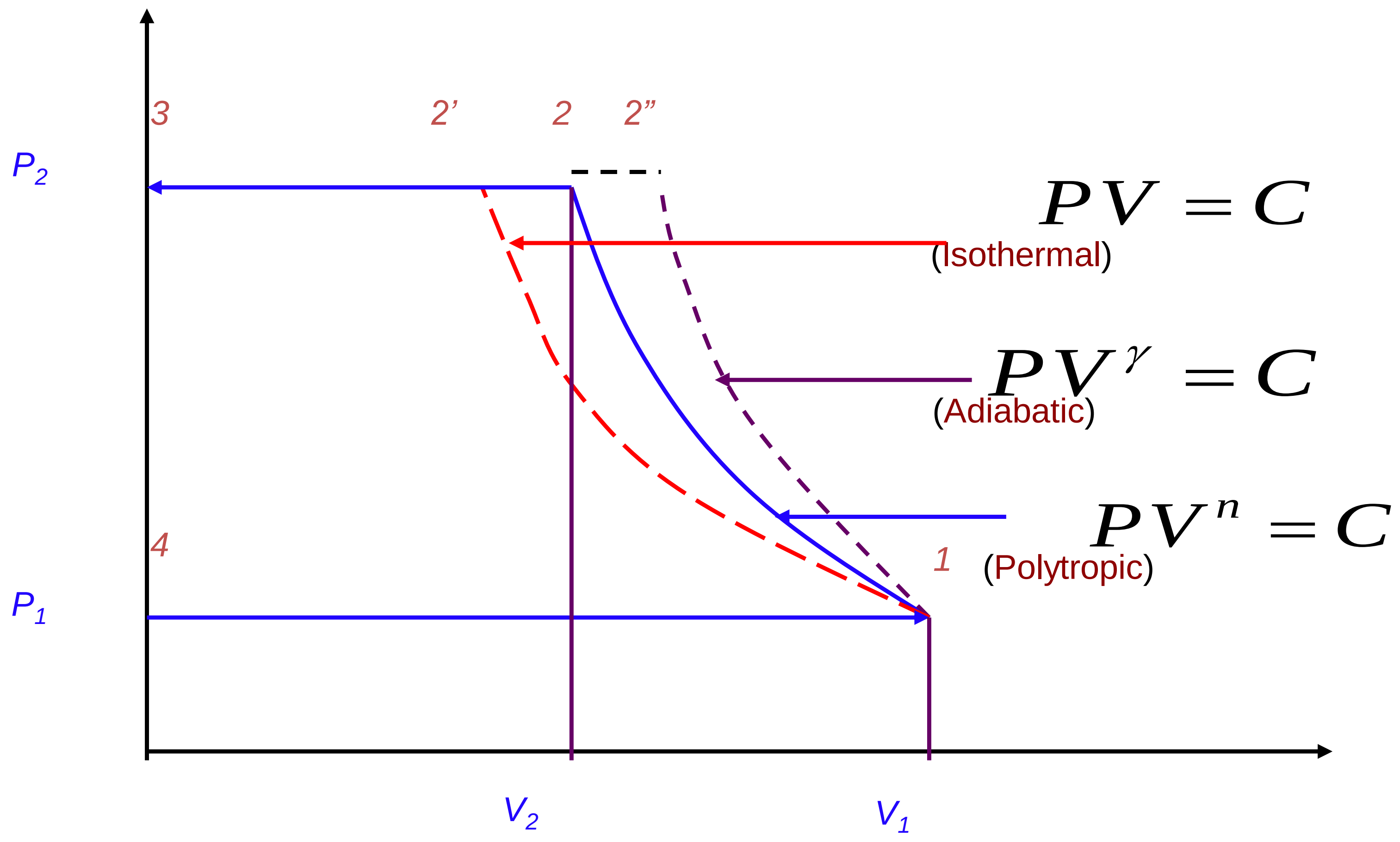
$\Longrightarrow$ 1 – 2’ : Isothermal Compression = Min. Work.

Reciprocating Compressor – Equation for Work

Thus, comparison between the Isothermal Work and the Actual Work is important.

Isothermal Efficiency, $\eta_{iso} = \dfrac{\text{Isothermal Work}}{\text{Actual Work}}$

Thus, more the Isothermal Efficiency, more the actual compression approaches to the Isothermal Compression.



Actual Work = W_{act} = Area 4-1-2-3-4

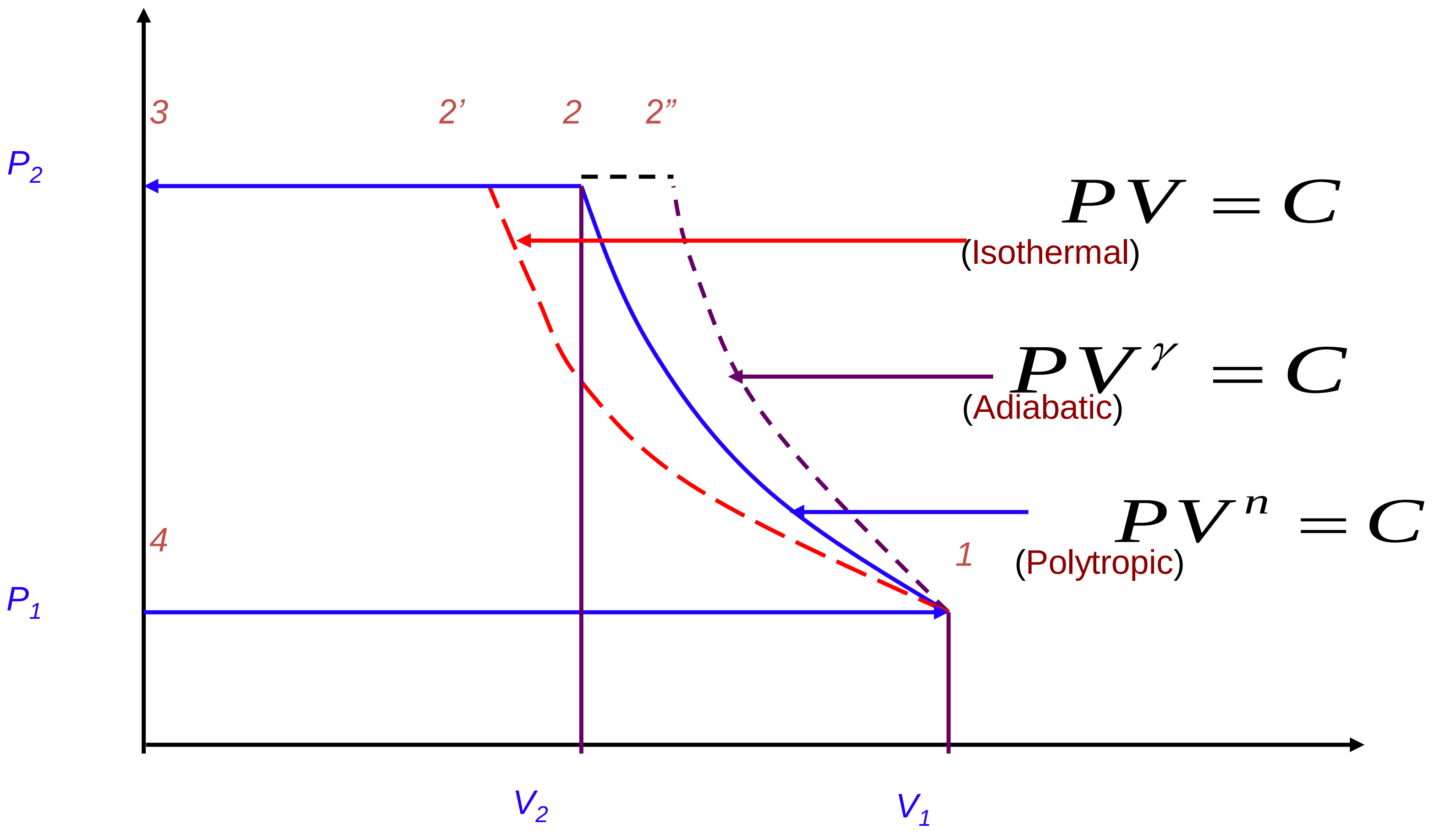
W_{act} = Area (4-1) – Area (1-2) – Area (2-3)

$$= P_1V_1 - \frac{P_2V_2 - P_1V_1}{n-1} - P_2V_2$$

$$= \left(P_1V_1 - P_2V_2\right) - \left(\frac{P_2V_2 - P_1V_1}{n-1}\right)$$

$$= \left(P_1V_1 - P_2V_2\right) + \left(\frac{P_1V_1 - P_2V_2}{n-1}\right)$$

Reciprocating Compressor – Equation for Work



$$W_{iso} = \left(1 + \frac{1}{n-1}\right)\left(P_1V_1 - P_2V_2\right)$$

$$= \left(\frac{n}{n-1}\right)\left(P_1V_1 - P_2V_2\right)$$

$$= \left(\frac{n}{n-1}\right) P_1V_1 \left(1 - \frac{P_2V_2}{P_1V_1}\right)$$

Now,

$$P_1V_1^{\,n} = P_2V_2^{\,n}$$

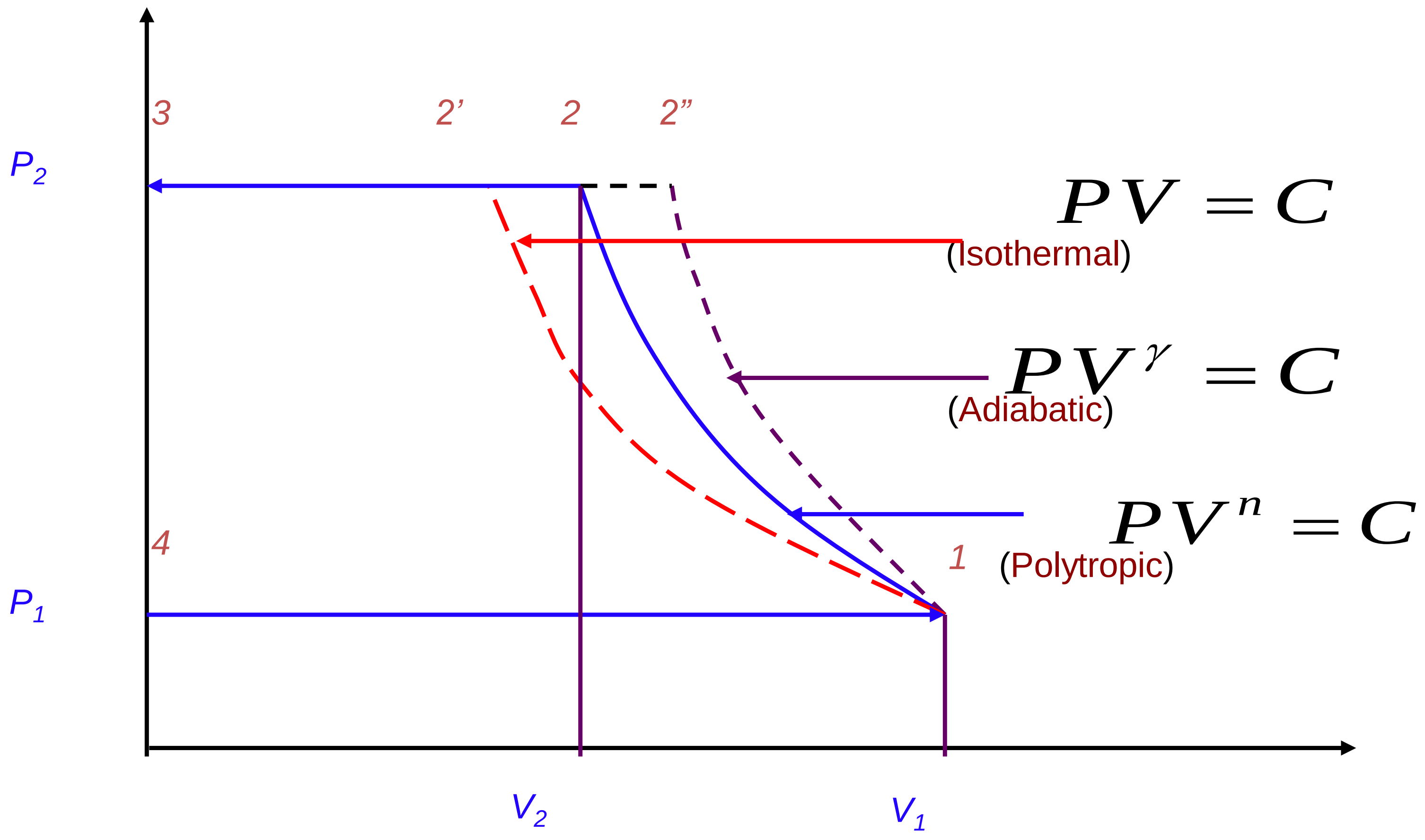
$$\Rightarrow \quad \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/n}$$

$$W_{iso} = \left(\frac{n}{n-1}\right) P_1V_1 \left\{1 - \frac{P_2}{P_1}\left(\frac{P_1}{P_2}\right)^{1/n}\right\}$$

Reciprocating Compressor – Equation for Work

$$W_{iso} = \left(\frac{n}{n-1}\right) P_1V_1 \left\{1 - \frac{P_2}{P_1}\left(\frac{P_1}{P_2}\right)^{1/n}\right\}$$

$$= \left(\frac{n}{n-1}\right) P_1V_1 \left\{1 - \frac{P_2}{P_1}\left(\frac{P_2}{P_1}\right)^{-1/n}\right\}$$



$$W_{iso} = \left(\frac{n}{n-1}\right) P_1V_1 \left\{1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right\}$$

$$W_{iso} = \left(\frac{n}{n-1}\right) mRT_1 \left\{1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right\}$$

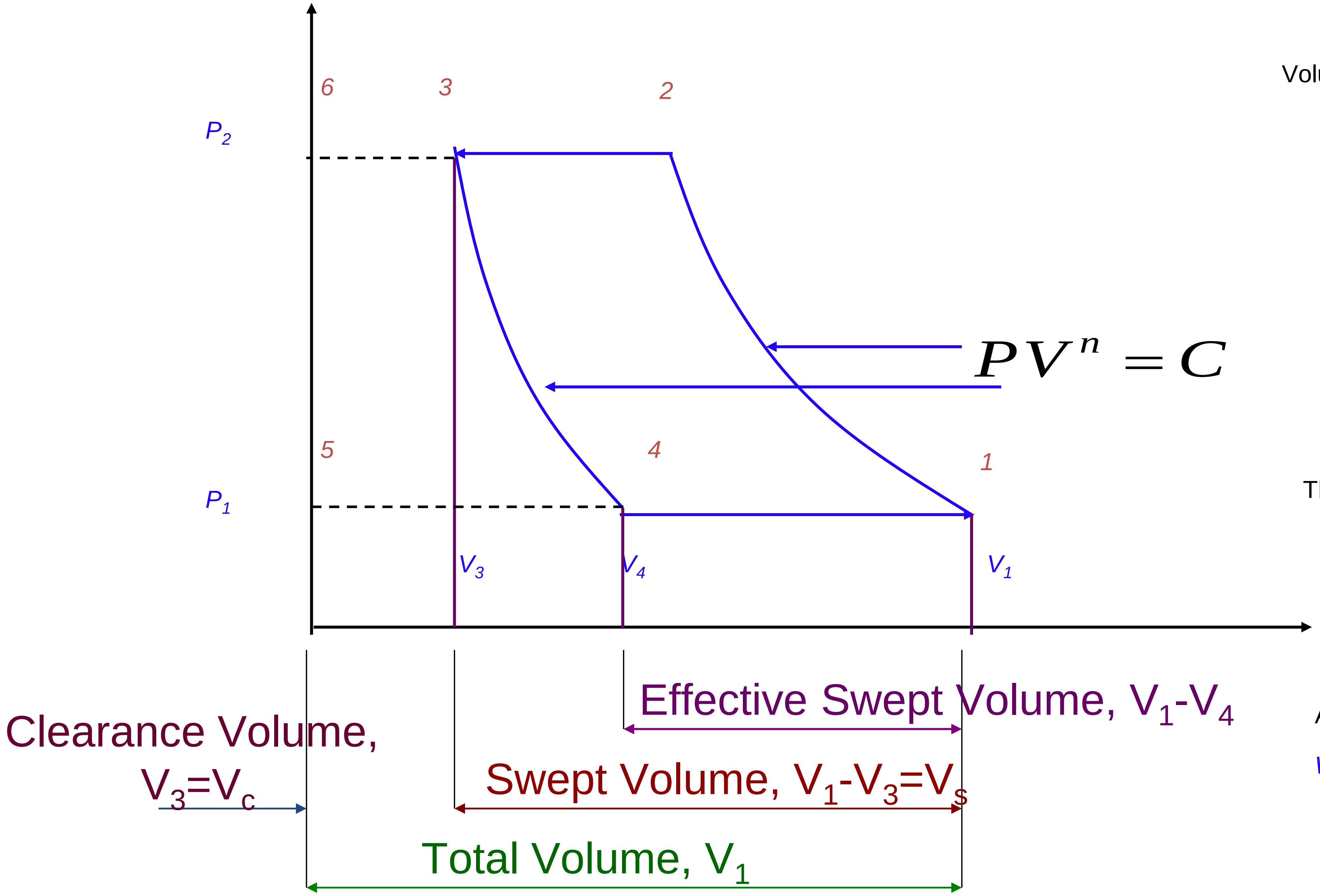
Delivery Temperature,

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

The solution of this equation is always *negative*.

This shows that Work is done *ON* the Compressor.

Reciprocating Compressor – Equation for Work



Clearance Volume :

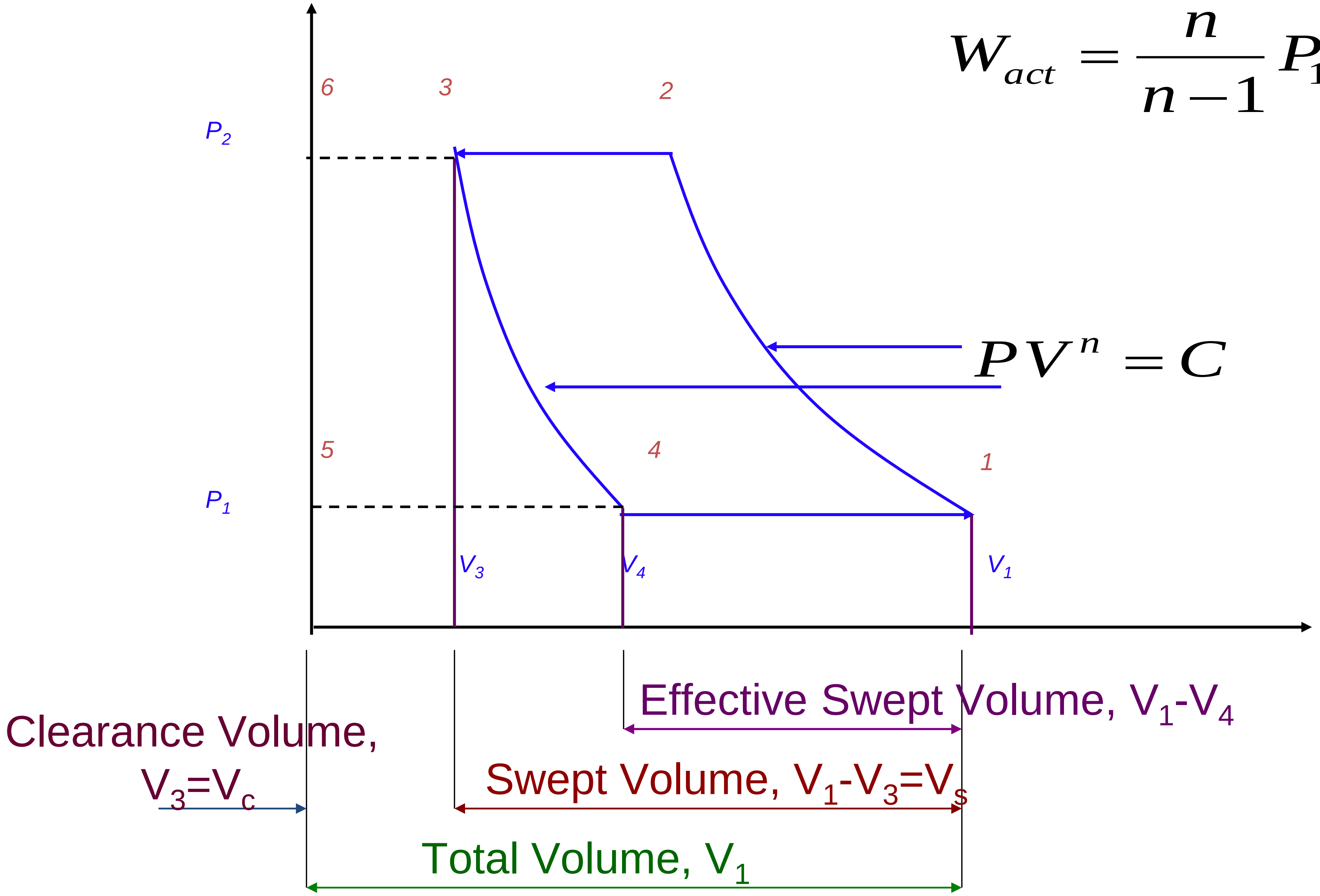
Volume that remains inside the cylinder after the piston reaches the end of its inward stroke.

Thus, *Effective Stroke Volume* = $V_1 – V_4$

Actual Work = W_{act} = Area 1-2-3-4

W_{act} = Area (5-1-2-6) – Area (5-4-3-6)

Reciprocating Compressor – Equation for Work



$$W_{act} = \frac{n}{n-1} P_1 V_1 \left\{ 1 - \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{n}} \right\} - \frac{n}{n-1} P_4 V_4 \left\{ 1 - \left(\frac{P_3}{P_4} \right)^{\frac{m-1}{n}} \right\}$$

$$\Rightarrow \quad W_{act} = \frac{n}{n-1} P_1 V_1 \left\{ 1 - \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{n}} \right\} - \frac{n}{n-1} P_1 V_4 \left\{ 1 - \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{n}} \right\}$$

$$W_{act} = \left(\frac{n}{n-1} \right) P_1 (V_1 - V_4) \left\{ 1 - \frac{P_2}{P_1} \left(\frac{P_1}{P_2} \right)^{1/n} \right\}$$

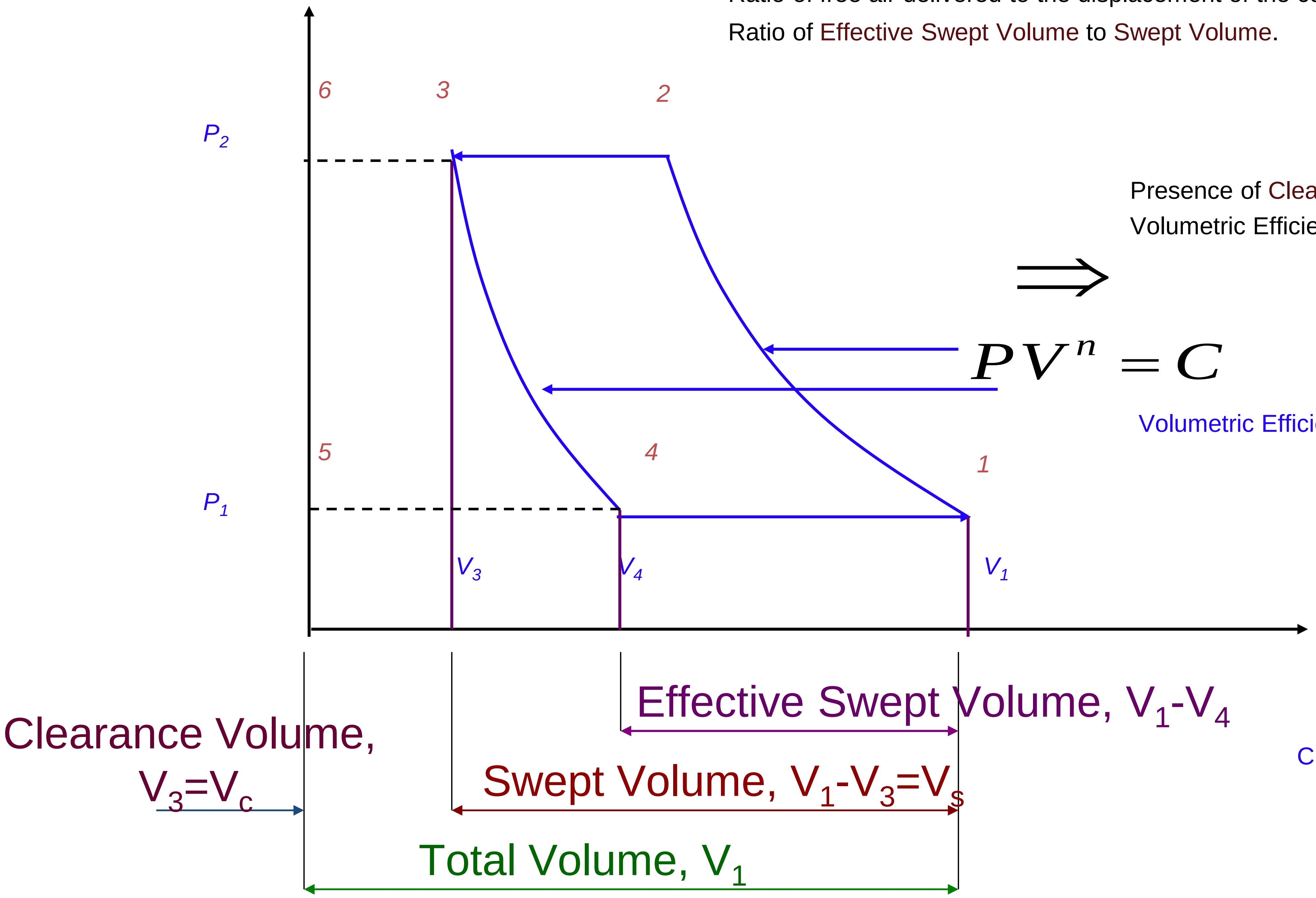
But, $P_4 = P_1$ and $P_3 = P_2$

Reciprocating Compressor – Volumetric Efficiency

Volumetric Efficiency :

Ratio of free air delivered to the displacement of the compressor.

Ratio of Effective Swept Volume to Swept Volume.



Presence of Clearance Volume

$\Rightarrow$ Volumetric Efficiency less than 1. (60 – 85 %)

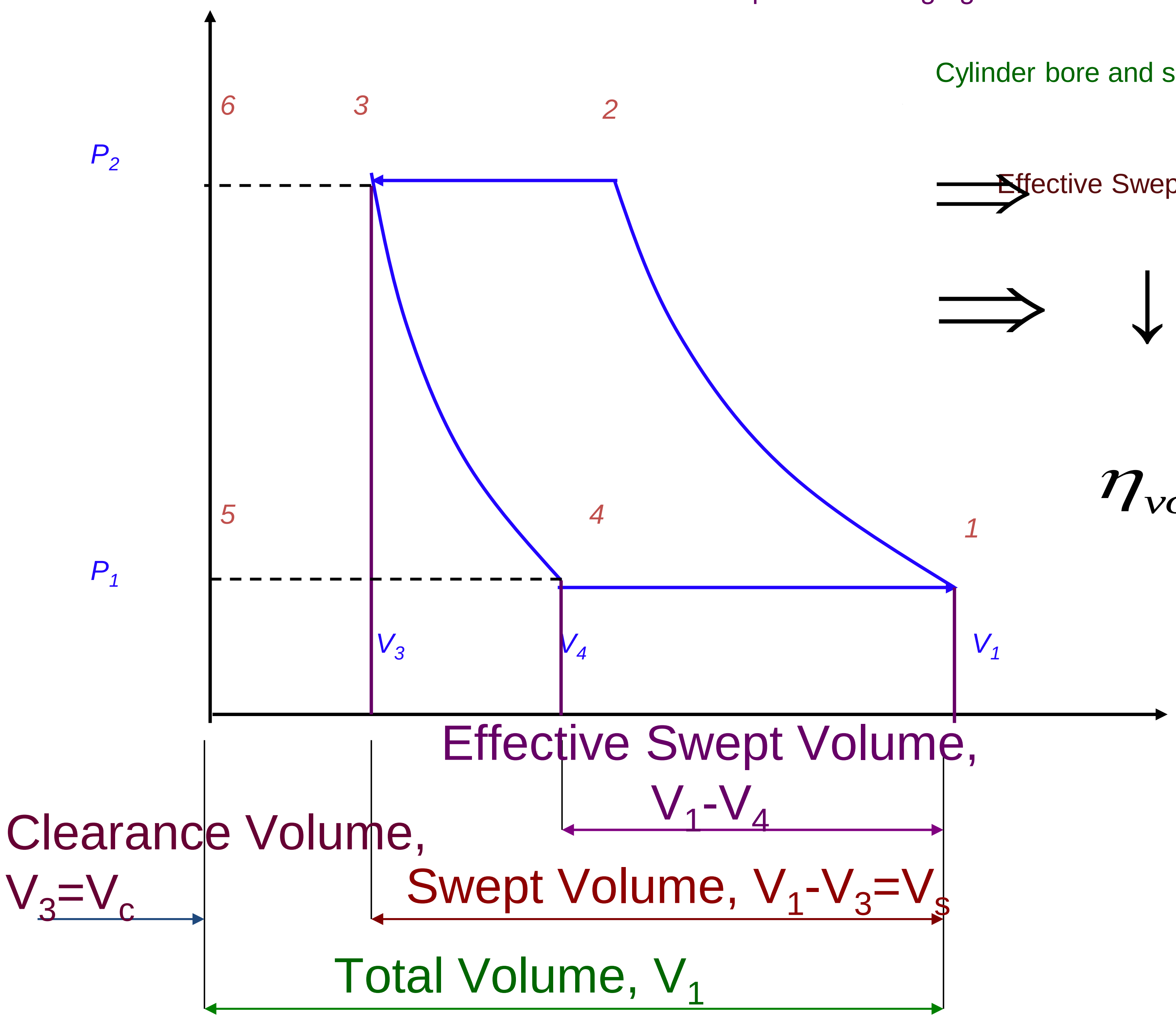
$$\text{Volumetric Efficiency} = \frac{\text{Effective Swept Volume}}{\text{Swept Volume}} = \frac{V_1 - V_4}{V_1 - V_3}$$

$$\text{Clearance Ratio} = \frac{\text{Clearance Volume}}{\text{Swept Volume}} = \frac{V_c}{V_s} = \gamma \qquad (4 – 10 \%)$$

Reciprocating Compressor – Volumetric Efficiency

↑ Pr. Ratio ↑ Effect of Clearance Volume

….Clearance air expansion through greater volume before intake



Cylinder bore and stroke is fixed.

⇒ Effective Swept Volume (V1 – V4) ↓ with ↑ Pr. Ratio

⇒ ↓ Volumetric Efficiency

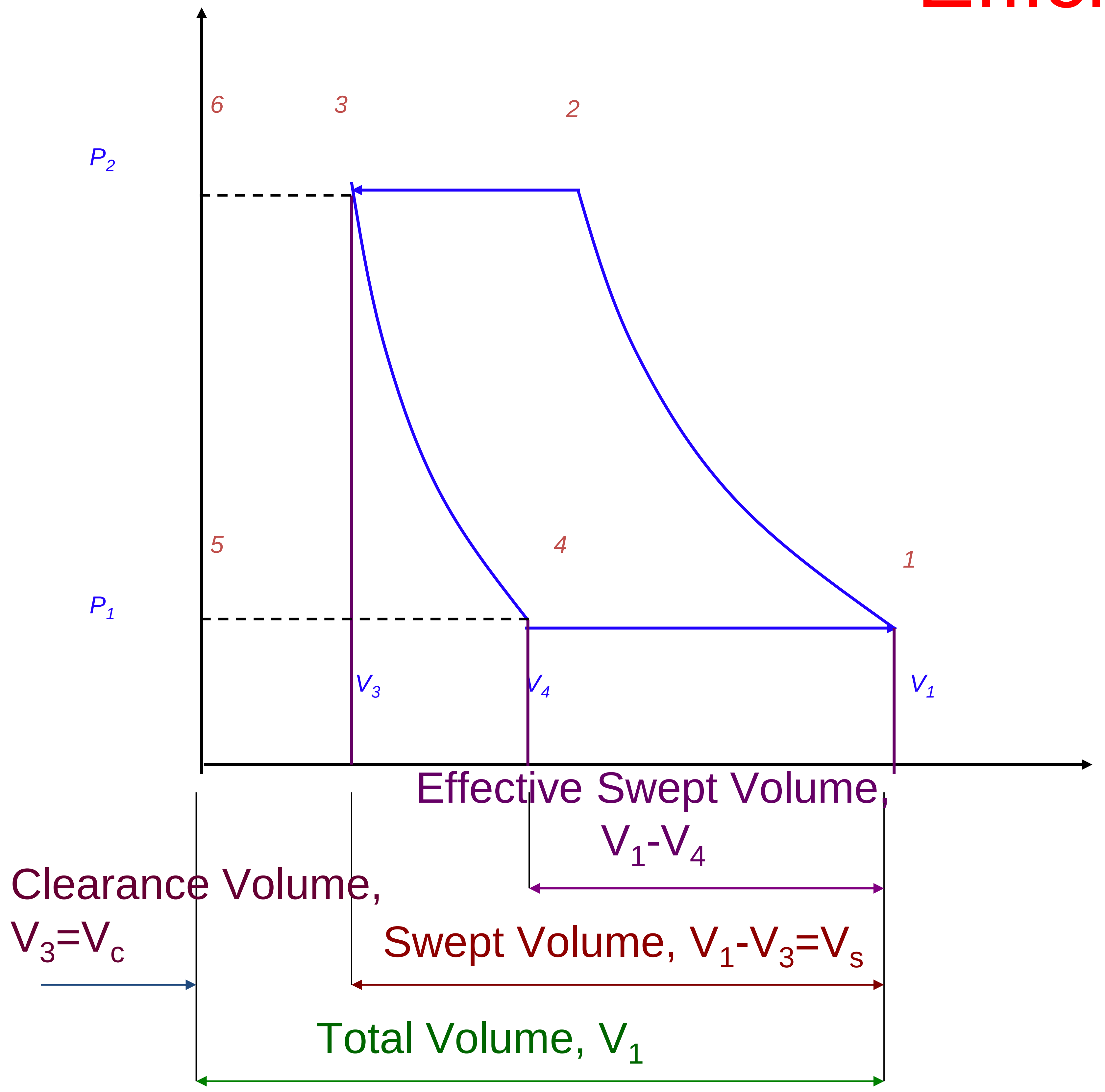
$$\eta_{vol} = \frac{V_1 - V_4}{V_1 - V_3}$$

$$= \frac{(V_1 - V_3) + (V_3 - V_4)}{(V_1 - V_3)} = 1 + \frac{V_3}{(V_1 - V_3)} - \frac{V_4}{(V_1 - V_3)}$$

$$= 1 + \frac{V_3}{(V_1 - V_3)} - \frac{V_4}{(V_1 - V_3)} \bullet \frac{V_3}{V_3}$$

$$= 1 + \frac{V_3}{(V_1 - V_3)} - \frac{V_3}{(V_1 - V_3)} \bullet \frac{V_4}{V_3}$$

Reciprocating Compressor – Volumetric Efficiency



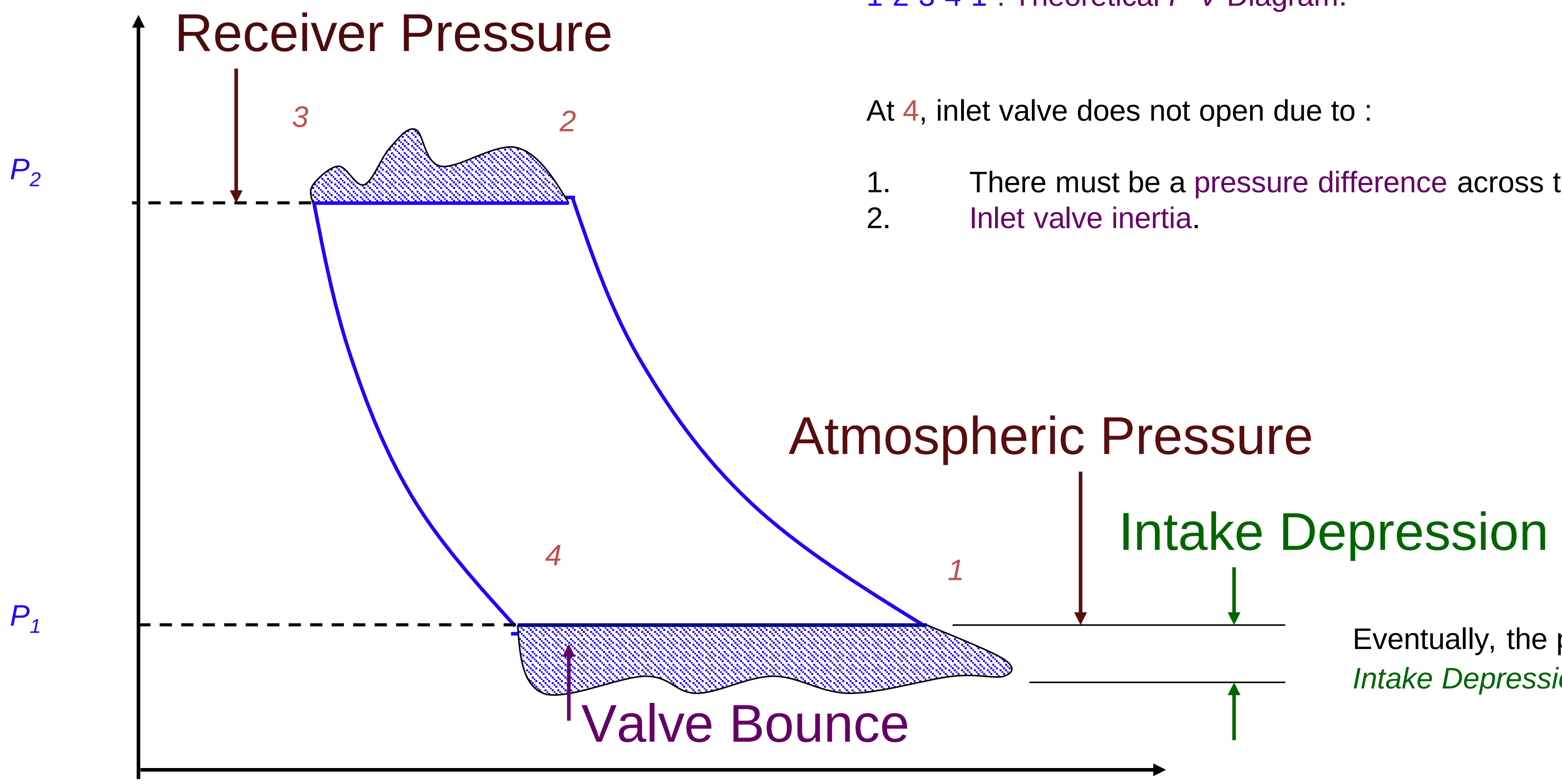
$$\eta_{vol} = 1 + \frac{V_3}{V_1 - V_3}\left(1 - \frac{V_3}{V_4}\right)$$

$$\eta_{vol} = 1 - \frac{V_3}{V_1 - V_3}\left(\frac{V_3}{V_4} - 1\right)$$

$$\eta_{vol} = 1 - \frac{V_3}{V_1 - V_3}\left(\left(\frac{P_3}{P_4}\right)^{1/n} - 1\right)$$

$$\eta_{vol} = 1 - \gamma \bullet \left(\left(\frac{P_3}{P_4}\right)^{1/n} - 1\right)$$

Reciprocating Compressor – Actual *P-V* Diagram



1-2-3-4-1 : Theoretical *P-V* Diagram.

At 4, inlet valve does not open due to :

1. There must be a pressure difference across the valve to open.
2. Inlet valve inertia.

Pr. Drop continues till sufficient level for valve to force its seat.

Some *valve bounce* is set (wavy line).

Eventually, the pressure sets down at a level *lower than* atmospheric pressure. This negative pressure difference is known as *Intake Depression.*

Similar situation appears at 2, i.e. at the start of the delivery.

Pressure rise, followed by valve bounce and then pressure settles at a level *higher than* the delivery pressure level.

Air delivery to a tank / receiver, hence, generally known as *Receiver Pressure*.