SHS

AIRs - LM in
General Physics 1
Quarter 2 – Week 8
Module 8B- Thermodynamic Process

General Physics 1

Grade 11/12 Quarter 2 - Module 8B - Thermodynamic Process

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General Physics 1

Quarter 2 – Week 8

Module 8B - Thermodynamic Process

Target

The concepts of work, heat and the internal energy of a system are related by the first law of thermodynamics, which is an expression of the law of conservation of energy. A person's body contains internal energy. When this person undergoes rigorous exercises, part of this energy is used for the workout, and part is lost in the form of heat carried off by evaporating sweat.

Figure 1

https://www.google.com/search?q=physical+fitness+picture+of+a+person+doing+exercise&num=10&tbm=isch&source=iu&ictx=1&fir=gFx1YqBLm6HP1M%252CT6JngfWBcmSuxM%252C_&vet=1&usg=AI4_-kTquQ2zTN5ets

At the end of this lesson you are expected to:

1. Interpret PV diagrams of a thermodynamic process. STEM_GP12GLTIIh-60

2. Compute the work done by a gas using dW=PdV. STEM_GP12GLTIIh-61

3. State the relationship between changes internal energy, work done and thermal energy supplied through the First Law of Thermodynamics. STEM_GP12GLTIIh-62

4. Differentiate the following thermodynamic processes and show them on a PV diagram: isochoric, isobaric, isothermal, adiabatic, and cyclic. STEM_GP12GLTIIh-63

Jumpstart

Activity 1: We are RELATED!

Direction: Read and understand the text to prepare you for the concepts that you will learn!

Thermodynamics is the branch of physics that is built upon the fundamental laws that heat and work obey. We have studied heat and work as separate topics. These two often, however, occur simultaneously. For example, in an automobile engine, fuel is burned at a high temperature. Some of its internal energy is used for doing the work of driving the pistons up and down, and the excess heat is removed by the cooling system to prevent overheating.

In thermodynamics, the collection of objects on which attention is being focused is called the ***system***. While everything else in the environment is called the ***surroundings***. For example, the system in an automobile engine could be the burning gasoline, while the surroundings would then include the pistons, the exhaust system, the radiator, and the outside air. The system and its surroundings are separated by walls of some kind.

Forces can do work and that work can change the potential and kinetic energy of the object. For example, the atoms and molecules of a substance exert forces on one another. As a result, they have kinetic and potential energy. These and other kinds of molecular energy are the *internal energy* of a substance. When a substance participates in a process involving energy in the form of heat and work, the internal energy of the substance can change. This relationship between heat, work and changes in the internal energy is known as the **first law of thermodynamics**, and is illustrated in figure 1 above.

Comprehension check!

DIRECTION: Read each statement below carefully and fill in the blank(s) with the correct word/s.

1. An example of a system is the __________.
2. Everything the surrounds the system is called __________.
3. __________,4.__________,5.__________,6.__________ are examples of surroundings for the burning fuel.
7. Q represents __________.
8. W represents __________.
9. ΔU represents __________.

10.__________states the relationship between changes in internal energy, work and thermal energy.

Discover

Suppose that a system gains heat *Q* and that this is the only effect occurring. The internal energy of the system increases from an initial value to a final value, $\Delta U = U_f - U_i = Q$. That is consistent with the law of conservation of energy. Work can also change the internal energy of a system. If a system does work *W* on its surroundings and there is no heat flow, energy conservation indicates that the internal energy of the system decreases from initial to final , $\Delta U = U_f - U_i = - W$. A system can gain or lose energy simultaneously in the form of heat *Q* and work *W*. The change in internal energy due to both factors is given by the equation:

$$\Delta U = U_f - U_i = Q - W$$

Thus, the ***first law of thermodynamics*** is just the conservation of energy principle applied to heat, work, and the change in the internal energy.

Q is positive when the system gains heat and negative when it loses heat.

W is positive when work is done by the system and negative when work is done on the system.

So positive *Q* adds energy to the system and positive *W* takes energy from the system. Thus $\Delta U = Q - W$. Note also that if more heat transfer into the system occurs than work done, the difference is stored as internal energy. Heat engines are a good example of this—heat transfer into them takes place so that they can do work.

PV Diagram

Consider a gas sealed in a container with a tightly fitting yet movable piston as seen below. We can do work on the gas by pressing the piston downward, and we can heat up the gas by placing the container over a flame or submerging it in a bath of boiling water. When we subject the gas to these thermodynamics processes, the pressure and volume of the gas can change.

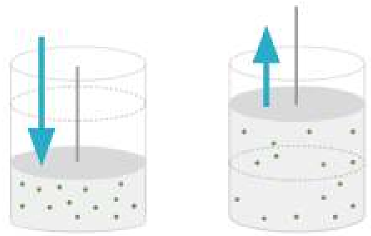


Figure 2

https://www.khanacademy.org/science/physics/thermodynamics/laws-of-thermodynamics/a/what-are-pv-diagrams

A convenient way to visualize these changes in the pressure and volume is by using a Pressure Volume diagram or **PV diagram** for short. Each point on a PV diagram corresponds to a different state of the gas. The pressure is given on the vertical axis and the volume is given on the horizontal axis.

Every point on a PV diagram represents a different state for the gas (one for every possible volume and pressure). As a gas goes through a thermodynamics process, the state of the gas will shift around in the PV diagram, tracing out a path as it moves (as shown in the figure below).

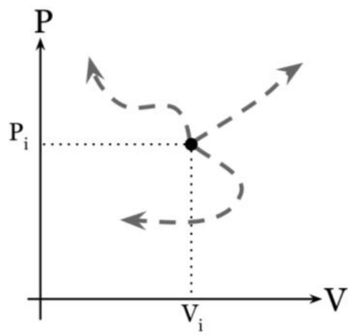


Figure 3

https://www.khanacademy.org/science/physics/thermodynamics/laws-of-thermodynamics/a/what-are-pv-diagrams

Being able to decode the information shown in a PV diagram allows us to make statements about the change in internal energy ΔU, heat transferred Q, and work done W on a gas. In the sections below, we'll explain how to decipher the hidden information contained in a PV diagram.

THERMAL PROCESSES

A system can interact with its surroundings in many ways, and the heat and work that come into play always obey the first law of thermodynamics. There are four common thermal processes. In each case, the process is assumed to be *quasi-static*, which means that it occurs slowly enough that a uniform pressure and temperature exist throughout all regions of the systems at all times.

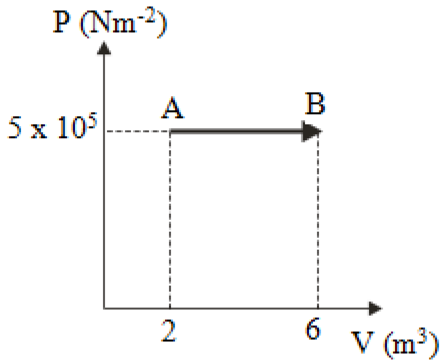
An **Isobaric process** is a thermodynamic **process** in which the pressure stays constant: $\Delta P = 0$. The heat transferred to the system does work, but also changes the internal energy of the system.

An everyday example of an isobaric process is boiling water in an open container. When heat energy is supplied to the water, the temperature rises and turns into steam. The steam has a higher temperature and occupies a greater volume, however, the pressure remains constant. From the start the pressure is equal to atmospheric pressure.

PV graph is a horizontal line.

Sample problem

1. PV diagram below shows an ideal gas that undergoes an isobaric process. Calculate the work done by the gas in the process AB.



Known :

Pressure (P) = 5 x 105 N/m^2

Initial volume (V_i) = 2 m^3

Final volume (V_f) = 6 m^3

Wanted : Work (W)

Solution :

$W = P (V_f - V_i)$

$W = (5 \times 10^5)(6 - 2) = (5 \times 10^5)(4)$
$W = 20 \times 10^5 = 2 \times 10^6$ Joule

A thermodynamic process taking place at constant volume is known as the **isochoric process**. It is also sometimes called as an isometric process or constant-volume process. The term isochoric has been derived from the Greek words "iso" meaning "constant" or "equal" and "choric" meaning "space" or "volume."

An isochoric process is one for which,

$V_f = V_i (\Delta V = 0, dV = O)$

In such a process, the work done is zero (since $dW = P\,dV = 0$ when V = constant). Hence from the first law of thermodynamics

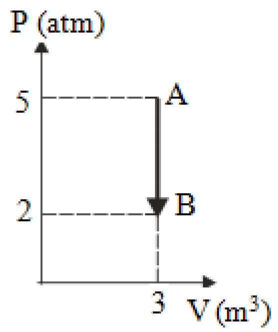
$dQ = dU$ (isochoric process)

The total heat supplied or rejected is also equal to the increase or decrease in the internal energy of the system.

PV diagram is a vertical line.

Sample problem

1. PV diagram below shows an ideal gas undergoes an isochoric process. Calculate the work done by the gas in the process AB.



Solution :
Process AB is an isochoric process (constant volume). The volume is constant so that no work is done by the gas.

$dW = PdV$
$dW = 3atm\,(0m^3) = 0$

The "**isothermal process",** is thermodynamic process in which the temperature of a system remains constant. The transfer of heat into or out of the system happens so slowly that thermal equilibrium is maintained. "Thermal" is a term that describes the heat of a system. "Iso" means "equal", so "isothermal" means "equal heat", which is what defines thermal equilibrium.

During an isothermal process there is a change in internal energy, heat energy, and work, even though the temperature remains the same. Something in the system works to maintain that equal temperature. One simple ideal example is the Carnot Cycle, which basically describes how a heat engine works by supplying heat to a gas. As a result, the gas expands in a cylinder, and that pushes a piston to do some work. The heat or gas has to then be pushed out of the cylinder (or dumped) so that the next heat/expansion cycle can take place. This is what happens inside a car engine, for example. If this cycle is completely efficient, the process is isothermal because the temperature is kept constant while pressure changes.

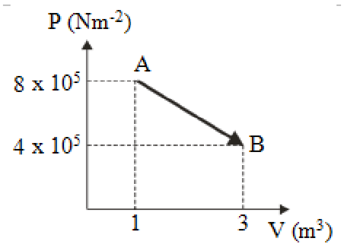
To understand the basics of the isothermal process, consider the action of gases in a system. The internal energy of an *ideal gas* depends solely on the temperature, so the change in internal energy during an isothermal process for an ideal gas is also 0. In such a system, all heat added to a system (of gas) performs work to maintain the isothermal process, as long as the pressure remains constant. Essentially, when considering an ideal gas, work done on the system to maintain the temperature means that the volume of the gas must decrease as the pressure on the system increases.

PV diagram is a rectangular hyperbola.

Sample problem

1. PV diagram below shows an ideal gas that undergoes an isothermal process. Calculate the work done by the gas in the process AB.

Solution



Work done by a gas is equal to the area under the PV curve

AB = triangle area + rectangle area

$W = [\frac{1}{2} (8 \times 10^5 – 4 \times 10^5)(3-1)] + [4 \times 10^5 (3-1)]$

$W = [\frac{1}{2} (4 \times 10^5)(2)] + [4 \times 10^5 (2)]$

$W = [4 \times 10^5] + [8 \times 10^5]$

$W = 12 \times 10^5$ Joule

The work done by the gas in the process AB = 12×10^5 Joule

An **adiabatic process** is defined as the thermodynamic process in which there is no exchange of heat from the system to its surrounding neither during expansion nor during compression.

PV diagram is a steep hyperbola.

The adiabatic process can be either ***reversible or irreversible.*** Following are the essential conditions for the adiabatic process to take place:

- The system must be perfectly insulated from the surrounding.
- The process must be carried out quickly so that there is a sufficient amount of time for heat transfer to take place.

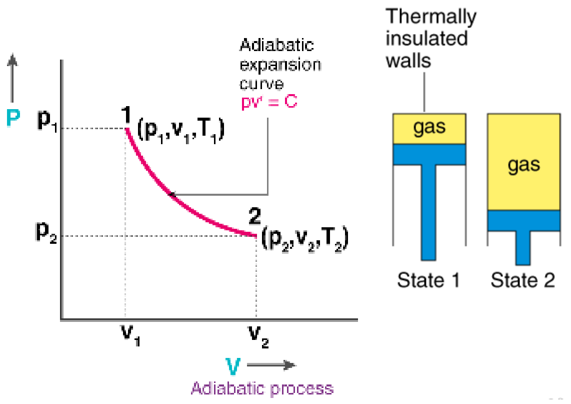


Figure 4

https://byjus.com/physics/adiabatic-process/

Following is the adiabatic process equation:

PV^{γ} = constant

Where,

- P is the pressure of the system
- V is the volume of the system
- γ is the adiabatic index and is defined as the ratio of heat capacity at constant pressure C_p to heat capacity at constant volume C_v

Sample problem

We often have the experience of pumping air into bicycle tyre using hand pump. Consider the air inside the pump as a thermodynamic system having volume V at atmospheric pressure and room temperature, 27°C. Assume that the nozzle of the tyre is blocked and you push the pump to a volume 1/4 of V. Calculate the final temperature of air in the pump? (For air , since the nozzle is blocked air will not flow into tyre and it can be treated as an adiabatic compression).

Solution:

Here, the process is adiabatic compression. The volume is given and temperature is to be found.

$T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}$.

$T_i = 300\ K \quad (273+27°C = 300\ K)$

$$T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}.$$

$$T_i = 300\ K \quad (273+27°C = 300\ K)$$

$$V_i = V \;\&\; V_f = \frac{V}{4}$$

$$T_f = T_i \left(\frac{V_i}{V_f}\right)^{\gamma-1} = 300\ K \times 4^{1.4-1} = 300K \times 1.741$$

T2 ≈ 522 *K* or 2490C

This temperature is higher than the boiling point of water. So it is very dangerous to touch the nozzle of blocked pump when you pump air.

Cyclic processes is a thermodynamic process in which the thermodynamic system returns to its initial state after undergoing a series of changes. Since the system comes back to the initial state, the change in the internal energy is zero. In cyclic process, heat can flow in to system and heat flow out of the system. From the first law of thermodynamics, the net heat transferred to the system is equal to work done by the gas.

$Q_{net} = Q_{in} - Q_{out} = W$ (for a cyclic process)

In the PV diagram the cyclic process is represented by a closed curve.

Let the gas undergo a cyclic process in which it returns to the initial stage after an expansion and compression as shown in Figure 5.

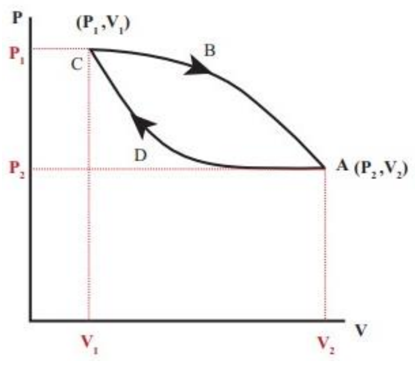


Figure 5: PV diagram for a cyclic process

Let W_i be the work done by the gas during expansion from volume V_i to volume V_f. It is equal to area under the graph CBA as shown in Figure 6.

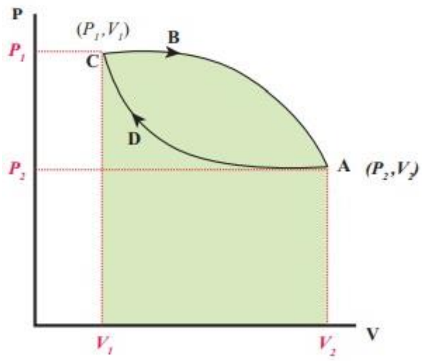


Figure 6: W for path ABC

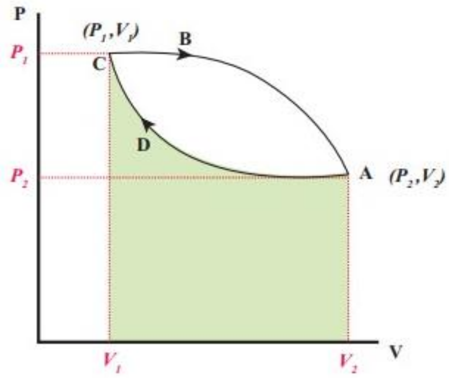


Figure 7: W for path ADC

Let W_f be the work done on the gas during compression from volume V_f to volume V_i. It is equal to the area under the graph ADC as shown in Figure 7.

The total work done in this cyclic process = $W_i - W_f$ = Green shaded area inside the loop, as shown in Figure 8.

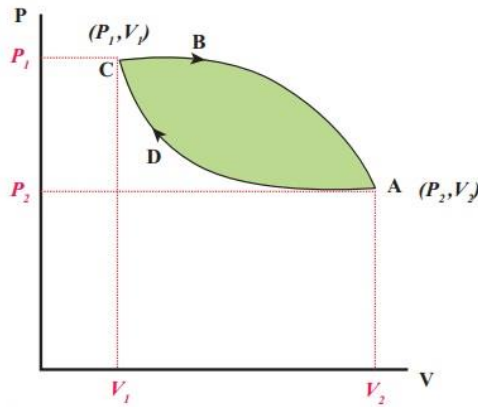
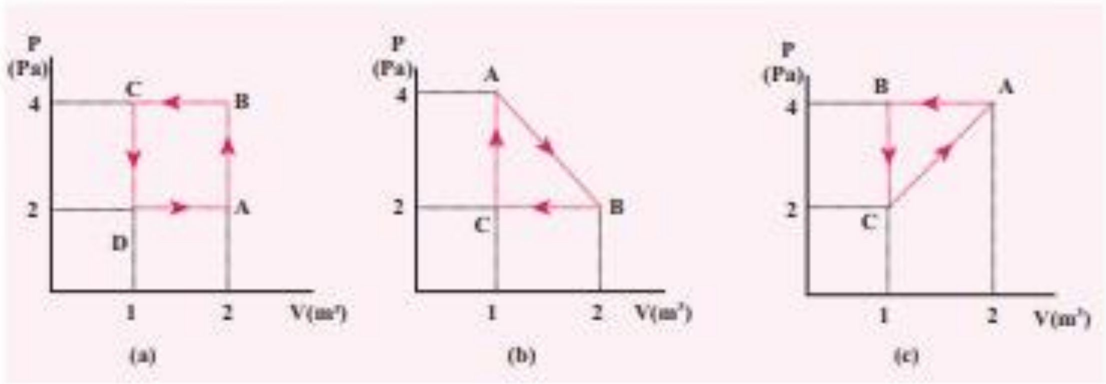


Figure 8: Net work done in a cyclic process

Thus the net work done during the cyclic process shown above is not zero. In general the net work done can be positive or negative. If the net work done is positive, then work done by the system is greater than the work done on the system. If the net work done is negative then the work done by the system is less than the work done on the system.

Sample problem

1. The PV diagrams for a thermodynamical system is given in the figure below. Calculate the total work done in each of the cyclic processes shown.



Solution:

In case (a) the closed curve is anticlockwise. So the net work done is negative, implying that the work done on the system is greater than the work done by the system. The area under the curve BC will give work done on the gas (isobaric compression) and area under the curve DA (work done by the system) will give the total work done by the system.

Area under the curve BC = Area of rectangle BC12 = $1 \times 4 = -4J$
Area under the curve DA = $1 \times 2 = +2J$
Net work done in cyclic process = $-4 + 2 = -2$ J

In case (b) the closed curve is clockwise. So the net work done is positive, implying that the work done on the system is less than the work done by the system. Area under the curve BC will give work done on the gas (isobaric compression) and area under the curve AB will give the total work done by the system.

Area under the curve AB = rectangle area+ triangle area = $(1\times2) + 1/_2 \times 1\times2 = +3J$
Area under the curve BC = rectangle area = $1 \times 2 = -2J$
Network done in the cyclic process = 1 J, which is positive.

In case (c) the closed curve is anticlockwise. So the net work done is negative, implying that the work done on the system is greater than work done by the system. The area under the curve AB will give the work done on the gas (isobaric compression) and area under the curve CA (work done by the system) will give the total work done by the system.

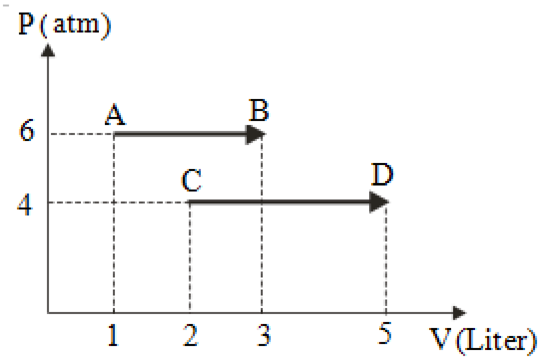
The area under the curve AB =Rectangle of area = $4 \times 1 = -4J$

The area under the curve CA = Rectangle area + triangle area = $(1\times2) + 1/2 \times 1\times2 = +3J$ The total work in the cyclic process = -1 J. It is negative.

Explore

Activity 2

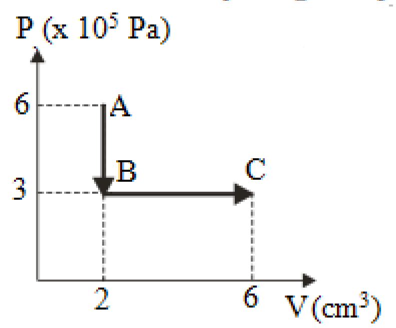
Direction: Compute for the difference of the work done by the gas in process AB and process CD.? Interpret the PV diagram in process AB and process CD.



Deepen

Activity 3

DIRECTION: Interpret the PV diagram and compute for the work done by the gas in process ABC.



Gauge

DIRECTION: Choose the letter of the best answer. Write your answer on a separate sheet.

1. A piston-cylinder device initially contains air at 150 kPa and 27°C. At this state, the volume is 400 litre. The mass of the piston is such that a 350 kPa pressure is required to move it. The air is now heated until its volume has doubled. Determine the total heat transferred to the air.
   A. 747kJ B. 757Kj C. 767Kj D. 777 Kj

2. A piston cylinder contains 0.5 kg of air at 500 kPa and 500 K. The air expands in a process so pressure is linearly decreasing with volume to a final state of 100 kPa and 300 K. Find the work in the process.
   A. 56.1 Kj B. 66.1 Kj C. 76.1 Kj D. 86.1 Kj

3. Which of the following variables controls the physical properties of a perfect gas?
   A. pressure B. temperature C. volume D. A, B and C

4. The unit of temperature in S.I. units is ____________.
   A, Celcius B. Fahrenheit C. Kelvin D. Rankine

5. A closed system is one in which__________.
   A. mass does not cross boundaries of the system, though energy may do so
   B. mass crosses the boundary but not the energy
   C. neither mass nor energy crosses the boundaries of the system
   D. both energy and mass cross the boundaries of the system

6. Temperature of a gas is produced due to ____________.
   A. its heating value
   B. kinetic energy of molecules
   C. repulsion of molecules
   D. attraction of molecules

7. In an isothermal process, the internal energy of gas molecules __________.
   A. increases C. remains constant
   B. decreases D. shows unpredictable behavior

8. A gas is compressed in a cylinder by a movable piston to a volume one-half its original volume. During the process 300kJ heat left the gas and internal energy remained the same. The work done on gas in Nm will be __________.
   A. 300 Nm B. 300,000 Nm C. 30 Nm D. 3000 Nm

9. Isochoric process is one in which __________.

A. free expansion takes place
B. very little mechanical work is done by the system
C. no mechanical work is done by the system
D. all parameters remain constant

10. The first law of thermodynamics states that __________.

A. work done by a system is equal to heat transferred by the system
B. total energy of a system during a process remains constant
C. internal energy, work and heat remains constant
D. total energy of a system remains constant

11. First law of thermodynamics furnishes the relationship between __________.

A. heat and work
B. heat, work and properties of the system
C. various properties of the system
D. various thermodynamic processes

12. Energy can neither be created nor destroyed but can be converted from one form to another is inferred from__________.

A. zeroth law of thermodynamics
B. first law of thermodynamics
C. second law of thermodynamics
D. basic law of thermodynamics

13. In an isothermal process, the internal energy __________.

A. increases C. remains constant
B. decreases D. first increases then decreases

14. Change in internal energy in a closed system is equal to heat transferred if the reversible process takes place at constant __________.

A. pressure B. temperature C. volume D. internal energy

15. Addition of heat at constant pressure to a gas results in __________.

A. raising its temperature
B. raising its pressure
C. raising its volume
D. raising its temperature and doing external work

References

Printed Materials:

Cutnell, Johnson 2004: Physics Sixth Edition

Website:

https://www.google.com/search?ei=0UmZX4vTMaaUmAW44LvICw&q=PV+diagram+of+an+isobaric+process&oq=PV+diagram+of+an+isobaric+process&gs_lcp=CgZwc3ktYWIQAzIJCAAQyQMQFhAeMgYIABAWEB46BAgAEEdQ2SBY2SBg-jRoAHACeACAAZoBiAGkApIBAzAuMpgBAKABAaoBB2d3cy13aXrIAQjAAQE&sclient=psy-ab&ved=0ahUKEwjL_5b1i9fsAhUmCqYKHTjwDrkQ4dUDCA0&uact=5

https://physics.gurumuda.net/isochoric-thermodynamics-processes-problems-and-solutions.htm

https://physics.gurumuda.net/isothermal-thermodynamic-processes-problems-and-solutions.htm

http://www.brainkart.com/article/Cyclic-processes-and-PV-diagram-for-a-cyclic-process_36256/

https://www.khanacademy.org/science/physics/thermodynamics/laws-of-thermodynamics/a/what-are-pv-diagrams