SHORT QUESTIONS

1. Why is the earth not in thermal equilibrium with the sun?

Ans. Several things regulate the temperature but the 2 biggest factors are;

a) The oceans and
b) Atmosphere

Water is able to absorb and hold a lot of energy (heat from the sun) and give it off slowly, thus keeping the earth warm at night and moving warm water to cold regions, like the poles.

The atmosphere regulates temperature by allowing heat to radiate out into space, countered by green-house gasses that keep it in. Since the earth also have an albedo of 30-35 %, therefore the earth maintains a relatively constant temperature by being in radiative balance between the incoming short wave solar radiation and the outgoing long wave infrared radiation. Each of these, short wave and long wave, are modulated by clouds, the atmosphere, and the earth's surface such that a balance is achieved.

2. When a block with a hole in it is heated, why does not the material around the hole expand into the hole and make it small?

Ans. When a solid block is heated, its temperature increases and its molecules vibrate with greater amplitude due to the increase in average translational K.E of the molecules. If the block expands linearly, all of its dimensions will expand in proportion, including the dimensions of the hole. Expansion is more like stretching, it's not "growing" like extra material being added to the exposed surfaces.

Another way of thinking of this is to picture the block without a physical hole, just a circle drawn on it to represent the hole. When the block expands, the circle expands in proportion. If the hole had been there it would have expanded in exactly the same way as the circle, because the absence of material would not cause migration of material.

This is why it helps to heat a nut that won't budge off a bolt.

3. A thermometer is placed in direct sunlight. Will it read the temperature of the air, or of the sun, or of something else?

Ans. The thermometer reads the temperature of matter that it is in contact with it (in this case, air). Solar radiation from the Sun heats up anything, including a thermometer that is in the Sun, just as it heats up our body. The Sun's energy is absorbed by the thermometer, causing it to heat up, thus showing a higher temperature than the true air temperature. The thermometer does not directly display the temperature of the air at all, rather it shows the temperature of the sensing element, usually metal or glass. When the sensing element is placed in the sunlight, it is warmed considerably above the ambient air temperature. When the sensor is placed in the shade, it is only warmed by the air. That is why the air temperature is measured by thermometers placed in the shade.

4. The pressure in a gas cylinder containing hydrogen will leak more quickly than if it is containing oxygen. Why?

Ans. The velocity of gas related to its molar mass is given by an ideal gas equation;

$$V \propto \sqrt{\frac{1}{M}}$$

Let V_H and V_O be the velocities and M_H and M_O be the molar masses of the hydrogen and oxygen respectively. Then we can write;

$$V_H \propto \sqrt{\frac{1}{M_H}} \quad \Rightarrow \quad V_H = K\sqrt{\frac{1}{M_H}} \qquad (1)$$

&

$$V_O \propto \sqrt{\frac{1}{M_O}} \quad \Rightarrow \quad V_O = K\sqrt{\frac{1}{M_O}} \qquad (2)$$

By dividing relation (1) by (2), we get;

$$\frac{V_H}{V_O} = \frac{\sqrt{\frac{1}{M_O}}}{\sqrt{\frac{1}{M_H}}}$$

$$\frac{V_H}{V_O} = \sqrt{\frac{M_O}{M_H}} = \sqrt{\frac{16}{1}} = 4$$

$$\Rightarrow \quad V_H = 4\, V_O$$

Hence for same conditions of temperature, pressure, volume and number of moles, hydrogen being lighter gas has velocity 4 times greater than that of oxygen.

5. What happens to the temperature of a room in which an air conditioner is left running on a table in the middle of the room?

Ans. The temperature of the air goes up. Consider the room as a closed system. The only energy that may be entering or leaving the room is through the AC unit. The AC unit cools some of the air by pumping refrigerant (coolant) and heating up other air (typically that exhaust air would be sent outside). Heat from the pumps, fans and power cord adds to the average temp of the room.

6. When a sealed thermos flask bottle full of hot coffee is shaken, what are the changes, if any in;

a. The temperature of the coffee, and

b. The internal energy of the coffee.

Ans. When a sealed thermo flask full of hot coffee is shaken, the temperature of the coffee is increased. The temperature increases because of the fact that the work is done in shaking the liquid and that work done increases the kinetic energy of the molecules. Since temperature is the average translational kinetic energy of the molecules of a substance therefore temperature increases. Also the internal energy of the molecules increases because internal energy is a function of temperature and when temperature increases, the internal energy of the molecules also increases.

7. When an object is heated, not all the energy it absorbs goes into increasing the velocity of the molecules. Explain where does the remaining energy go?

Ans. The total energy of a molecule is given as;

Total energy = Kinetic energy + Potential energy

$E_T = K.E + P.E$

$E_T = K.E_{Trans} + K.E_{Rot} + K.E_{Vib} + P.E$

Hence when an object is heated, not all the energy it absorbs goes into increasing the velocity of the molecules but it is also consumed in increasing the rotational K.E, vibrational K.E and potential energy of the molecule.

8. Why does the pressure of the air in automobile tire increase if the automobile is driven for a while?

Ans. When automobile is driven, work is done against friction between the tire and ground. This work done against the force of friction heats up the tire and thus increases its temperature. Due to increase in the temperature of the tire, the temperature of the gas inside the tire also increases. Since the pressure of a gas is directly proportional to its temperature at a given volume, therefore when the automobile is driven, the pressure of the gas also increases with its temperature.

9. On removing the valve, the air escaping from a cycle tube cool. Why?

Ans. The air in a cycle tube is present at a pressure greater than the atmospheric pressure. When the valve is removed, the air expands suddenly i.e. adiabatic expansion ($\Delta Q = 0$) takes place and the temperature decreases, thus the air from the tube becomes cool.

Also from first law of thermodynamics;

$$\Delta Q = \Delta U + \Delta W$$

$$\Rightarrow \quad 0 = \Delta U + \Delta W$$

$$\Rightarrow \quad \Delta W = -\Delta U$$

Since internal energy is directly proportional to the temperature of a gas i.e.

$$\Delta U = n\,C\,\Delta T$$

Therefore the air from tube becomes cool due to decrease in the internal energy.

10. Can a room be cooled by leaving the door of an electric refrigerator open?

Ans. A room cannot be cooled by leaving the door of an electric refrigerator open, rather it will be heated if the doors and windows of the room are kept closed. In the thermal equilibrium stage, the refrigerator extracts heat from its cooling chamber, work is done on it by the electrical motor and the total energy is rejected by it to the surroundings. The same amount of energy is conducted to the cooling chamber. When the door is kept open, the cooling chamber and the surroundings become the same body. The refrigerator now takes heat from the room, work is done on it by the motor and the total is given to the room. Thus, the work done by the motor is added to the closed room, so it gets heated.

11. What are the conditions for a process to be reversible?

Ans. Conditions for Reversible Thermodynamic Process

The conditions required for a process to be reversible are:

i. The changes must take place at an infinitesimally slow rate.

ii. The system must always be in thermal and mechanical equilibrium with the surroundings.

iii. The net change at each stage in the combined entropy of the system and its surroundings should be zero.

iv. No energy losses due to friction.

For example, ice can be formed by withdrawing heat from water at 0 ^{0}C under normal pressure. Further, if heat is supplied at the same rate to ice at 0 ^{0}C under normal pressure water is formed at the same rate. Similarly water can be boiled into system at 100 ^{0}C under normal pressure by supplying heat. If the heat is withdrawn again at the same rate from the steam at 100 ^{0}C under the same pressure at condensation forming water.

12. Write the limitations of first law of thermodynamics.

Ans. Limitations of First Law of Thermodynamics

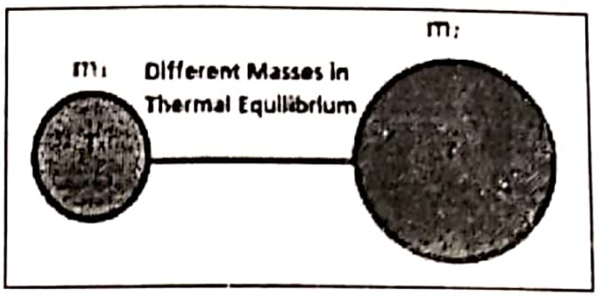
I. It does not tell us the direction of flow of heat, it only tells us that when two bodies of different temperatures are there in a closed system undergoing a cyclic process then the net heat change will be equal to work done, i.e. internal energy change is 0.

II. 1st law of thermodynamics predicts that heat can be completely converted in useful work which however is impossible in actual practice.

13. Is it possible, according to the second law of thermodynamics, to construct a heat engine that is free from thermal pollution?

Ans. No, it is not possible to construct a heat engine that will not expel heat into atmosphere. According to second law of thermodynamics, all the practical heat engines absorb heat from the source, convert a part of it in to mechanical work and reject the remainder to the cold body or atmosphere. Hence, no heat engine can operate with single source for conversion of heat energy into mechanical work without expelling heat to the atmosphere. In other words, there must be a temperature difference between the hot and cold bodies (source and sink) for the conversion of heat in to mechanical work.

14. When two systems are in thermal equilibrium, do they have the same amount of kinetic energy?



Ans. No. Two gaseous systems have the same amount of average translational kinetic energy PER PARTICLE.

The total kinetic energy will depend on the amount of matter present in each system. .

A solid has only vibrational energy not translational kinetic energy. Two systems are said to be in thermal equilibrium if they are at same temperature i.e., they have only same amount of average translational K.E. Consider a system which consists of two different masses m_1 and m_2 as shown in diagram. When the masses are brought in contact, they have same amount of average translational K.E but the total K.E is not the same.

15. Work can be converted completely into heat, so can heat be converted completely into work?

Ans. No, heat cannot be converted completely into work according to 2nd law of thermodynamics. When heat is converted into work, then;

I. System state is changed.
II. Efficiency is not 100 %.
III. Process cannot be operated indefinitely.
IV. Process must be performed in a CYCLE.

For isother.nal process in an ideal gas system; the internal energy of system will not change i.e.

$$\Delta Q = \Delta W \qquad (\Delta U = 0)$$

And heat has been converted completely into work, but the process involved the change of state of the gas. The volume increases and the pressure decreases until the normal pressure is reached, at which the process stops, so it cannot be used indefinitely. Therefore the system has to be brought back to initial state (i.e. a cycle), which involve a flow of heat to or from the system and the performance of work by or on the system to complete a cycle.

Thermal efficiency "η" is given by;

$$\eta = 1 - \frac{Q_C}{Q_H}$$

Where Q_C = heat rejected to low temperature reservoir

and Q_H = heat flowing from high temperature reservoir

Now if $Q_C = 0$, then;

$$\eta = 1 - \frac{0}{Q_H} = 1$$

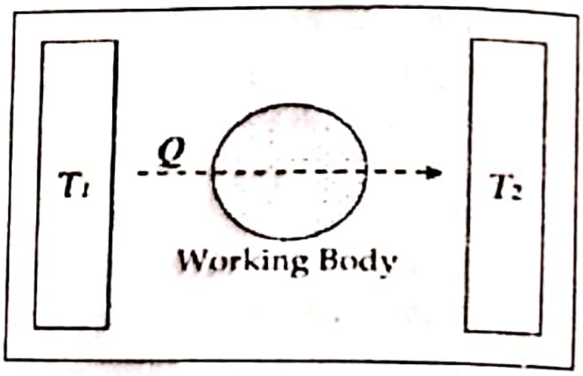
$$\Rightarrow \quad \eta = 100\ \%$$

Since efficiency of a heat engine is always less than 100 %, therefore Q_C amount of heat which is not converted to work is always rejected to low temperature reservoir. Hence heat cannot be converted completely into work.

16. Entropy has often called as "time arrow". Explain?

Ans. According to law of increase of entropy, "All natural processes where heat flows from one system to another, there is always a net increase in entropy".

It is observed that a natural process tends to proceed towards a state of greater disorder. Hence one can correlate entropy increase with the passage of time. One can calculate the entropy change ΔS for the passage of the quantity of heat Q from the temperature T_1, through the "working Substance" to the temperature T_2. Since;



$$S = \frac{Q}{T}$$

Then the entropy change or "equivalence-value" for this transformation is:

$$\Delta S = S_{final} - S_{Initial}$$

Which equals:

$$\Delta S = \left(\frac{Q}{T_2} - \frac{Q}{T_1}\right)$$

Thus, for example, if Q = 50 J, T_1 = 100 °C, and T_2 = 1 °C

Then;

$$\Delta S = \left(\frac{50}{1} - \frac{50}{100}\right) = (50 - 0.5) = 49.5\ J/°C$$

Then the entropy change for this process would be 49.5. Hence, entropy increased for this process. Thus we can say that increase in entropy describe the direction of time or increase in entropy is the arrow of time

17. Can specific heat of a gas be zero or Infinity? Can specific heat be negative?

Ans. Yes, the specific heat of a gas can be zero or infinity or negative. The specific heat of a gas is given by;

$$C = \frac{\Delta Q}{m\,\Delta T}$$

Consider that the gas is enclosed in an air-tight cylinder and frictionless piston.

I. Zero Specific Heat

Let the gas be suddenly compressed. In this case no heat is supplied to the gas but there is an increase in the temperature of the gas. Hence $\Delta Q = 0$ and therefore;

$$C = \frac{0}{m\,\Delta T} = 0$$

II. Specific Heat be Infinity

Let the gas be heated and allowed to expand. Suppose that the fall in temperature due to expansion is balanced by rise in temperature due to heat supplied. In this case ΔT = 0 and therefore;

$$C = \frac{\Delta Q}{m \times 0} = \infty$$

III. Specific Heat be Negative

Let the gas be heated and allowed to expand such that the fall in temperature due to expansion is greater than rise in temperature due to heat supplied. In this case ΔT is negative and therefore specific heat is also negative.

$$C = -\frac{\Delta Q}{m\,\Delta T}$$

18. An inventor claims to have developed a heat engine, working between 27 °C and 227 °C having an efficiency of 45 %. Is the claim valid? Why?

Ans. Given that

$$T_1 = 227 + 273 = 500\text{ K}$$

$$T_2 = 27 + 273 = 300\text{ K}$$

$$\eta = ?$$

$$\eta = 1 - \frac{T_2}{T_1}$$

$$\eta = 1 - \frac{300}{500} = 0.40$$

$$\eta = 0.40 \times 100\,\% = 40\,\%$$

Since according to the provided data the efficiency of the heat engine is 40% and not 45%, so his claim is not valid.