PROBLEM-BASED LEARNING IN BASIC PHYSICS - XI

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In this article— thirteenth in the series of articles— we present problems which are non-numerical or the ones which require minimum mathematics but can be addressed by bare minimum mathematics or simple logic. Many are the situations which have to be understood in the light of laws of physics. This involves serious discussion of the phenomenon or the process and logical analysis.

Keywords: Action-reaction pair, centre of mass, moment of inertia, Archimedes principle, surface tension, surface energy, field inside a charged spherical shell, real isotherm, phase isotherm on P-T diagram

1. **Motion relative to an Observer** Consider a passenger travelling by train. S/he performs an experiment of dropping two stones while standing near the door. One inside the train and other outside the train. What would be the trajectory of these stones. Where would be the stone land with respect to the door position where our passenger drops it. What will be the trajectory observed by an observer standing near the track for the stone dropped outside?

2. **Action and Reaction Forces**

   (a) Consider a person standing on the earth's surface and three forces in relation to his/her state of motion: (i) gravity acting on him/her, (ii) force his/her feet exert on the ground and (iii) normal reaction that ground exerts on him. Explain his state of rest and identify which two of the three forces form action-reaction pair.

   (b) Consider a horse cart. Consider the following forces: (i) force exerted by horse on the ground, (ii) force of friction between the diagram horse's feet and the ground, (iii) force exerted by the horse on the coupling between him and the cart, (iv) force exerted by the cart on the coupling and friction between cart wheel and the ground.

   Which of these forces form pair(s) of action and reaction?

3. Consider a bird in a cage hanging from a spring. Inside the cage, the bird is sitting on the swing. What will happen to the spring when the bird jumps off the swing and when it lands on the floor of the cage?

4. Consider two cylinders—one of bigger radius and hollow and the second of smaller radius. Initially the bigger cylinder is resting on the ground and the smaller cylinder is inside the bigger cylinder as Figure 1. Shows side view of cross-section of cylinders the smaller cylinder was released from its initial position. Discuss its subsequent motion.

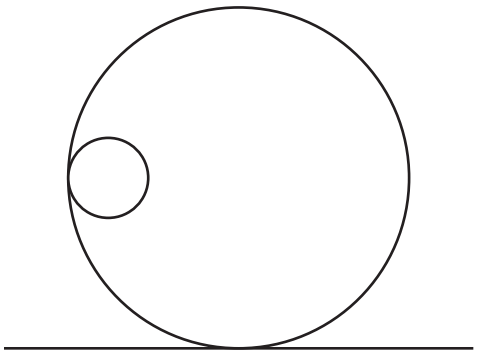

Figure. 1

5. Consider four objects, (i) a ring, (ii) a disc, (iii) a solid sphere, and (iv) a hollow sphere. All four are released from the same height on an inclined surface and they roll down without slipping. Which of them will be the first to reach the bottom of the plane? Why?

6. A vessel filled with water is kept on a weighing pan and the scale is adjusted to zero. A block of mass M and density ρ is suspended by a massless spring of spring constant k. This block is submerged inside the water in the vessel. What is the reading of the scale?

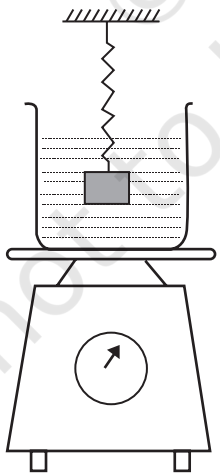

Figure. 2

7. A boat carrying a number of large stones is floating in a water tank that is about to overflow. If the stones are unloaded into the water tank, what will happen to the water level in the water tank? Will water in the tank overflow? Give scientific explanation based on Archimedes principle. (At a scientific meeting, the same question was put to Dr Gamow, Dr J. Robert Oppenheimer, and Nobel Laureate Dr Felix Bloch. All three of them, not thinking too carefully, gave the wrong answer!)

8. Liquid droplets take spherical shape as the sphere has minimum surface area for given volume thereby minimizing surface energy due to surface tension. However, kept on a horizontal surface, water droplets are nearly spherical whereas mercury drops gets flattened. Explain why?

9. Gravitational field inside a spherical shell of uniform mass density is zero. Explain.

10. Isotherms (P vs V curves at constant temperature) for a real substance are as shown in Figure 2. LPG (liquified petroleum gas) cylinders (the one carrying cooking gas for household) have liquified gas that works on the Principle of similar isotherms. which cooking,s when we open the regulator valve, it flows out in gaseous form is almost at a constant rate till all of it is consumed. Explain the working of as LPG cylinder using the isotherms shown below. You may assume that initially you are at the leftmost point of the horizontal section (mixture of liquid and vapour) of the isotherm.

11. Figure 3 shows phase diagram (P vs T behaviour) for water. We want to understand two phenomenon associated with our life using this phase diagram.

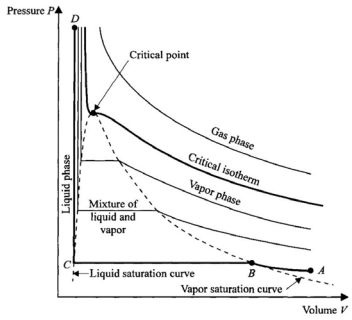

Figure. 3: Isotherms of pure substance such as H_2O

(a) We use water inside pressure cooker for cooking food. Explain how pressure cooker works and what is the advantage of using it.

(b) During summers in India, one of the common practice to keep cool is to make ice balls of crushed ice, dip it in flavoured sugar syrup and sip it. For this a stick is inserted into crushed ice and is squeezed by the palm to make it into the ball. Equivalently in winter, in those areas where it snows, people make snow balls and throw around. Explain the formation of balls out of crushed ice or snow in the light of P–T diagram of water.

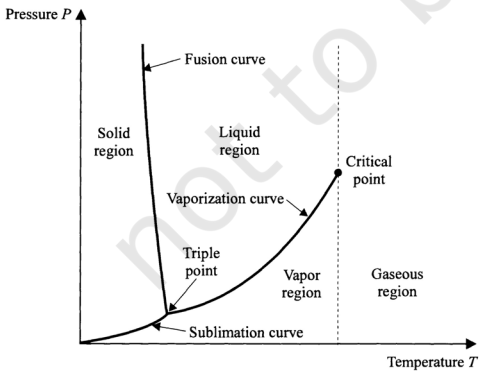

Figure. 4 :Phase diagram for water (H2O)

Discussion/Answers

1. It is our common experience while travelling in a train that any object dropping off our hand falls at our feet. This is what will happen to the stone dropped inside the train. The stone dropped outside likewise should also drop exactly below the feet of the passenger at the door and near the track. For an external observer, when the stone was dropped, it already had horizontal speed (that of the train), and thus would fall vertically like a projectile projected horizontally along a parabolic path.

It is worth noting that water or paper dropped outside from the moving train appears to go backward because as seen from the outside they had horizontal speed and being lighter objects would face air resistance slowing their speed. Thus, for internal observer, they appear to move backward.

Also note here, that during this time, if the train suddenly accelerates or decelerates, these objects will appear to move opposite to acceleration of the train creating need for pseudo force to explain their motion as train accelerating becomes a non-inertial frame.

2. (a) For a person standing on the ground, him/her exerting force on the ground and normal reaction from the ground are action-reaction pairs. As these forces always act on the other body from the pair of bodies interacting with each other.

(b) For the horse and cart, horse pushing the ground backward and friction pushing the horse forward are the action-reaction pairs. Also, horse pulling the cart through coupling and cart pulling the coupling backward are the action-reaction pairs.

3. As the bird jumps off the swing, in trying to preserve position of the centre of mass of bird-cage system, spring will contract. Since bird has jumped on the floor of the cage under the action of gravity, eventually the centre of mass gets lowered.

4. As the smaller cylinder is released, it will roll down due to gravity, but as there is no force in the horizontal direction, horizontal position of centre of mass should remain the same. As the smaller cylinder descends, its centre of mass shifts to the right and the bigger cylinder will roll towards left to preserve position of combined centre of mass.

5. For an object rolling without slipping kinetic energy is given by $\frac{1}{2}\left(1+\frac{1}{R^2}\right)Mv^2$. Since all

start with the same potential energy, which gets converted to kinetic energy, the one with smallest moment of inertia will have largest speed. Since solid sphere has the smallest moment of inertia for same mass and radius, it will be the first to reach the bottom. Same can also be argued based on acceleration.

Let x be the compression on the spring. As the block is in equilibrium $Mg-(K_z+P_wV_g)=0$

where ρ_w is the density of water and *V* is the volume of the block. The reading in the pan is the force applied by the water on the pan i.e.,$M_{vssel}l+m_{water}r+p_wVg$.

Since the scale has been adjusted to zero without the block, the new reading is ρ_wVg^1

6. For a floating object, mass of the liquid displaced is equal to its own weight.

Whereas for a submerged object, volume of the liquid displaced is equal to volume of the submerged object. Stone is much denser than water and thus has much smaller volume compared to the water having same mass. Thus, when stone is in the floating boat, volume displaced is much more (as equivalent mass of water occupies much greater volume) than when it is dropped into the water. Thus, the tank will not overflow. In fact its water level should come down.

7. When a liquid droplet is on a horizontal surface, the sum of its energy: gravitational potential energy plus surface energy should settle for a minimum. Since mercury is much denser and has greater mass within same volume compared to water. Thus, lowering its centre of mass reduces its gravitational energy much more than that of water droplet. Flattening of the droplet lowers energy of mercury droplet and compensates for increase in surface energy more than water droplet. The flattened droplet is the minimum of total energy for mercury.

8. Refer to the figure below. If the big circle represents thin uniform spherical shell and P a point inside, then the entire spherical surface can be divided into pairs of infinitesimal areas dA_1 and dA2. In this case contribution to the field at P from infinitesimal elements will be proportional to $dA/r^2 = d\Omega$, the solid angle subtended at P,

since mass of each element is proportional to area for a shell. Since, each element subtends same solid angle at P and field

directions are opposite, net field at P or any point inside is zero.

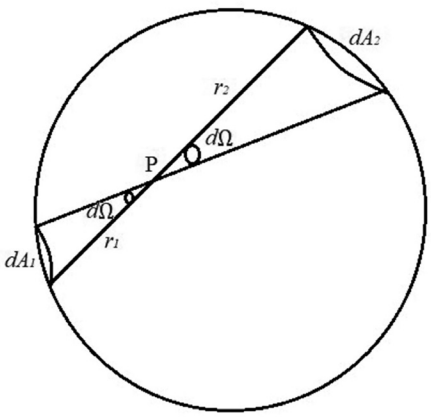

Figure.5

9. Refer to the figure in the question, the horizontal portion represents mixture of liquid and vapour phase. This is the state of LPG inside the cylinder. As we open the regulator, some gas escape could reduce pressure. Simultaneously some liquid evaporates and tries to maintain the pressure. The state point on the horizontal portion shifts to the right. This continues till all of the LPG gets converted to gas. This brings the system to the rightmost point of the horizontal segment. Here onwards, pressure starts dropping indicating we are running out of LPG.

10. Phase diagram problems:

    (a) Refer to the vaporisation curve. To the left is the liquid phase and right is the vapour phase. Initially we start with water-liquid phase and as it is heated, slowly water gets converted to steam and a fraction of the substance shifts horizontally crossing vaporization curve. This results in increasing pressure. So on PT diagram increase in pressure brings us back to liquid phase. This means further vapourisation is prevented unless temperature is increased further, i.e., boiling point is increased due to increase in pressure. How is this advantageous?

For normal cooking, water boils at 100°C, using 540 Cal/gm of energy. If boiling point is raised by increasing pressure, then vapor isation is prevented till further increasing in temperature. Say, If new boiling temperature is 110°C, then we need only 10 Cal/gm before we cross 110°C instead of losing 540 Cal/gm. This is where we not only save our energy but food also gets cooked better. Normally people allow steam to be released (in the form of whistle) which is actually loss of energy as we are releasing steam. Correct thing to do is the just before steam is released, stove should be kept on the minimum flame to prevent loss of heat energy and then food gets cooked better at higher temperature, also preventing loss of 530 Cal/gm. This would also result in saving cooking fuel. This is the advantage of pressure cooker.

(b) Refer to the P-T diagram of water and fusion curve. Say, we are having crushed ice at 0°C and we are on the left of the fusion curve. Increasing pressure at 0°C and 1 atm, we move our state vertically upward and convert ice into liquid state and decreasing

pressure in liquid state at 0°C and 1 atm converts water to ice state. When crushed ice is squeezed, some of it melts filling up the gap between ice flakes. Upon releasing pressure, this water freezes binding all ice flakes making the ball more stable.

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