Changes during Evaporation

About 500 years ago, an Italian artist and engineer Leonardo da Vinci showed that water bodies are crucial resources of any country and by stopping flow of river one country can even harm its neighbours. Yet he argued that evaporation takes away the water from one country and passes it on to another country. It ensures that….no one can really own the water!

Summary

Evaporation is a widely prevalent phenomena in our environment. It is a concept which is familiar to almost everyone. Yet, science education research shows that many students don't fully understand the changes that take place during evaporation and properties of substance that don't change during evaporation. For example, our daily life experience shows that water disappears on evaporation, but where does it go? Tons of water evaporates around us and is carried by air and yet we do not feel air becoming heavier! This leads to an apparent idea that water becomes lighter or massless when it goes in air. This learning unit tries to explore some of these notions related to evaporation.

From a pedagogy perspective, it is important here for students to first express what they know about evaporation and predict what they expect in certain situations. Then the students actually try out the tasks and see if their predictions turn out to be correct or incorrect. When student's predictions come out to be correct or incorrect, student learning is enhanced by the initial step of predicting and articulating their original thinking before trying it out. In **Task 1**, they explore the concept of mass transfer in evaporation process. **Task 2** helps in gathering evidence for heat transfer during the evaporation process. **Task 3** explores the rate of evaporation for some common liquids, why the rate is important and on what all factors it depends on.

Minimum Time Required: 4 sessions of 40 min each
Type of Unit: Laboratory Based

Requirement

Nail polish remover or Acetone, Glycerine, Ethanol or Spirit, Water,
Stop Watch or wall clock, Digital weighing Balance (least count 10 mg or 1 mg), Conical flask (100 cm^3) with rubber cork
Thermometer (0˚C to 100˚C), Droppers
Cotton or Paper napkin, Beaker (100 mL), Brown paper, Rubber band (small size)

Links to Curriculum: Related to Chapter on States of Matter/ Matter in our surroundings in Class IX textbooks.
Matter transfer, Heat transfer, Temperature, Rate of evaporation, Molecular force of attraction

Learning Objectives:

1) To appreciate that evaporation is a valuable phenomenon in our lives and its understanding can help us in several situations.

2) To get an evidence for mass conservation during evaporation and thus for gases having mass.
3) To understand evaporation at molecular level.
4) To get an evidence for evaporative cooling, and indirectly gaining competence.
5) To understand that rate of evaporation is different for different liquids, and changes with surface area of liquid-gas interface.

Q 1. Have you seen evaporation in your surrounding? If yes, can you write any two examples?

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The students can write any two example here such as: drying of clothes, making of salt in salt pans, drying of spilled water on floor, drying of roads after rains.

Q 2. What do you observe when a liquid evaporates in a container? Do you see any change happening which indicates evaporation is taking place?

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Here it is important to highlight that we don't see the evaporation actually taking place. All we observe is the disappearance of a liquid. Historically, many philosophers reasoned that water bodies lose water which is sucked up by the sun. Many said it is wind which carries away water, and without sun and wind, no evaporation can take place. Only with several indirect evidences collected in 17th century, we have started to infer its nature and the changes taking place during evaporation, particularly loss of thermal energy from a system and reduction in mass of the liquid system.

Fill in the blank to complete the sentence: The process of a liquid ______________ ____ at the liquid gas interface is called **evaporation**.

changing to vapour phase (or gaseous phase)

Q 3. What are the factors that you know which affect evaporation?

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Nature of liquid, Surface area, air flow, temperature, humidity in the air.
Every liquid can be turned into a gas if enough energy is available to the molecules constituting the liquid. The energy needed by molecules depends on factors such as the type of liquid or its temperature. At a higher temperature, and with higher area of liquid-gas interface, and at higher flow rate of air, evaporation is higher. If the air already has vapour of the liquid, then net rate of evaporation would be lower. When the air is saturated with the vapour, there would be no net evaporation.

Q 4. a) When do you sweat?
b) If you don't wipe it, how can you dry it?

c) What happens to that sweat when it dries?
d) After it has dried where can you find it?

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> Here it would be useful to remind students of the conditions where sweating is observed: they may say summer, or after heavy exercise, or under stress, near fire, in sunlight, etc.
> Students may say that one can dry it by moving under a fan, going to an air-conditioned room, moving to a cool-shaded space where it slowly dries.
> The fate of sweat on drying is a valuable question which can reveal a lot of misconceptions if present among students. Realization that it is liquid which evaporates and moves to a vapour phase is goal. But students may say that the liquid simply disappears, or that it is destroyed. This leads to question where does the sweat go on disappearing. Sometimes students may say that it goes to atmosphere, some students also say that it becomes a part of clouds. Let students speak/ write whatever they think. Let students discuss their answers and reach a common understanding instead of you correcting it.

Task 1: Matter Transfer in Evaporation

Q5. If you take a liquid in a sealed flask and mass of this flask with the liquid is *m*. After some time, the liquid in the sealed flask evaporates. Predict if the mass of this flask will be still same as *m*, greater than *m* or less than *m*.

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> This step is very important for students to write **BEFORE** they do the experiment. There is no right or wrong answer here because it is prediction. Whether it is correct or not will be clear in further trial ahead.

What you need: Conical flask (100 cm^3) with rubber cork, a dropper, digital weighing Balance (least count 10 mg or 1 mg), Acetone (or Spirit or Nail polish remover, 2 mL).

Procedure:

1. Take a clean and dry conical flask and place a cork on it. Use a balance to measure its mass, and write it as m_1. Open the cork and smell the flask gently.
2. To this flask, add about 6 to 7 drops of acetone (or spirit or nail polish remover) using dropper and smell gently (do not take it near your nostrils and breathe heavily). Place the cork on the flask and seal it tightly. Use a balance to measure its mass and write it as m_2.
3. Warm the conical flask with hands and shake it till the liquid in it evaporates (do not invert the conical flask). Measure its mass again and write it as m_3.

4. Open the flask and smell gently. (Do not take it near your nostrils and breathe heavily), keep the flask open for 5 minutes. Close the flask by replacing the cork. Measure the mass of flask now and write it as m_4.

Record your observations in table below.

	Step 1	**Step 2**	**Step 3**	**Step 4**
Mass	**m_1 = _____ gm**	**m_2 =_____ gm**	**m_3 =_____ gm**	**m_4 =_____ gm**
Smell				

Q 6. Was the smell of the conical flask content before closing (Step 1) and after opening the cork (Step 4) same or different? What does this tell about the changes in air inside the flask?

> The smell is different and indicates presence of acetone vapour in step 4, which was not present in Step 1

Q 7. What does the flask contain after step 3 and before step 4? What physical state is it in?

> It contains air plus acetone vapour. These are in gaseous state at a pressure higher than the surrounding atmospheric pressure.

Q8. What happened to the air that was in the flask initially?

> It is still there in the flask.

Q 9. Is m_3 same as m_1 or m_2? Can you explain your result?

> If there is no leakage from the flask, then m_3 should be same as m_2, which indicates that the acetone that has evaporated is still in the flask. It is also important to realize that this acetone gas has a mass which is contributing to mass of the flask even now. Please note the flask also has air in it which also has mass and exerts gravitational force on the flask, but this force is balanced by buoyancy force of surrounding air and hence, the mass of air does not contribute to the masses of flask.
> If the closed flask is weighed under vacuum, then the mass of air would contribute to the mass of the flask.

Q 10. Is m_4 same as m_1 or m_2? Can you explain your result?

After step 3, the flask has air and acetone vapour with net pressure higher than the surrounding air. Therefore when the flask is opened, some of the air-acetone gaseous mixture will diffuse out of the flask. Thus, m_4 should be less than m_2. Keeping for longer time will lead to more loss of gaseous acetone from the flask, and thus eventually m_4 would be same as m_1.

Q 11a. Based on your results; which of the following statement(s) is/are true and which is /are false?

1) Evaporation converts liquid into gaseous phase. _______
2) Gases have mass.________
3) Gases can diffuse through air within few seconds._______
4) Movement from liquid to gaseous state decreases mass of its molecules.________

Q 11b. Give evidences to support your answer for each of the above answers.

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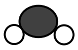
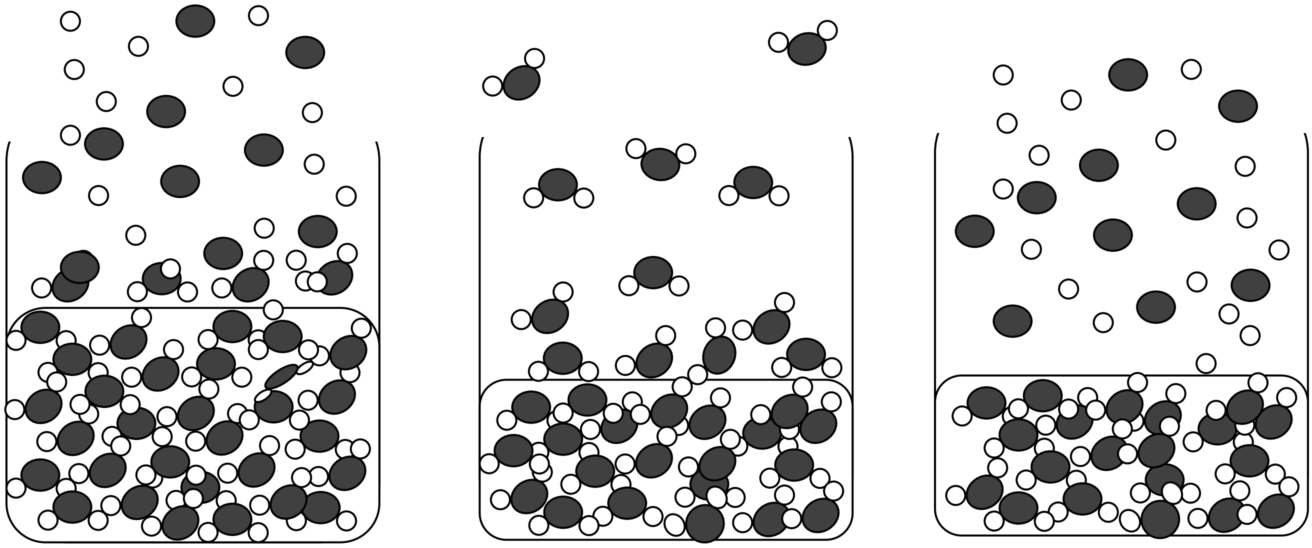
Statement 1 is true because our nose can smell only gaseous substances. Since there is strong smell of acetone after its disappearance as liquid in the flask, it suggests that the liquid acetone has been converted to gaseous phase.
Statement 2 is true because $m_3 = m_2$, within experimental error or at least $m_3 > m_1$. In other words, transformation of liquid acetone to gaseous acetone did not lead to loss of mass of the flask.
Statement 3 is true because as soon as we open cork of the flask, the acetone vapour can be smelled outside the flask instantaneously.
Statement 4 is False because $m_3 = m_2$, within the experiment error limit.

Our modern understanding of liquids suggest that molecules of a liquid are always moving. Even at a fixed temperature and pressure, different molecules have different amount of kinetic energy. In liquids, some molecules at the surface always have more kinetic energy than the others. Even at temperature much below its boiling point, some of its molecules have enough energy to break the forces of attraction and escape from the surface liquid in the form of vapour (or gas).

Students sometimes get confused between evaporation and boiling. Evaporation is a type of vaporisation that occurs on the surface of a liquid as it changes into gas. What differentiates it from boiling is that in boiling, vaporization takes place throughout the bulk of the liquid and it takes place at or above its boiling point. Evaporation is a surface phenomena which takes place at all temperatures. At boiling point or above, contribution of evaporation to vaporization is much less as compared to the faster boiling process.
In order to turn into a gas the molecules held together inside the liquid have to break free to get into the air. This means the bonds holding the molecules together need to be broken. Thus, molecules that form lots of bonds among themselves need a higher energy for evaporation. This also affects the boiling temperature of a liquid. Molecules

> that attract one another very strongly start to boil at higher temperatures compared with those that have weak attractions. Liquid with lower boiling point generally evaporate more quickly, and are known as volatile liquids.

Q 12. If  is water molecule then which of the following diagram represents evaporation of water? Justify your answer.



(A) (B) (C)

> Diagram (B) because during evaporation, molecules of water remain intact, they do not breakdown into atoms.

Task 2: Heat Transfer in an Evaporation

> Have you ever wondered why we sweat when our environment is hot or when we exercise? Sweating is a life-saving strategy that cools the body down and maintains its temperature. Without sweating, the body cannot regulate its temperature, which can lead to overheating or even heatstroke. But why does sweating have a cooling effect? In this activity you can observe this cooling power in action—ready to get cool?

When a liquid keeps on evaporating from its surface, the molecules remaining in liquid have lower average energy. This cools down the remaining liquid.

Q13. Why do people sprinkle water on open ground on a hot sunny day?

> Likely response from students is that water cools down the ground and surrounding air. Students may also think that this happens just because water is cooler than earth. They may not realize that it is not due to temperature of water which matters, but the cooling effect is due to heat absorbed by water in becoming vapour. It might be a good

prompt to help students recollect that there is an evaporation involved in this process. Next activity will help in understanding this.

Requirement: a thermometer (0˚C to 100˚C), cotton or paper napkin, a rubber band (small size), water in a small beaker or small container, blower (optional).

Procedure:

1. Cover thermometer bulb with paper napkin or cotton from all sides (including bottom), put the rubber band to fix the paper napkin or cotton at place (As shown in Fig. I).

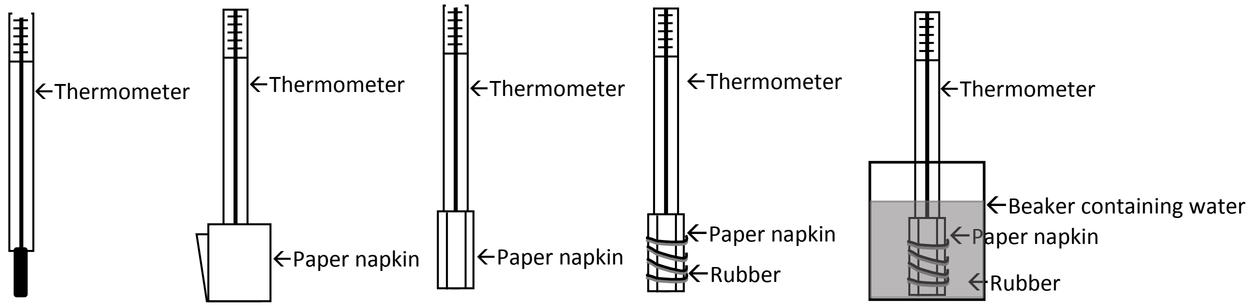


Fig. I

2. Note down the thermometer reading._____ **˚C.**

Here we observed that students try to shake the thermometer to get its reading to zero. This thinking they carry from household thermometers which are used to measure body temperature. It may be discussed that the thermometer would normally show the temperature of the room or of the object that is in contact with its bulb and thus will not reach a reading of 0°C, unless you put it in ice.
You may also need to show students how to read temperature in a thermometer.

3. Hold the thermometer in a hand, keeping the cotton / paper napkin on the thermometer bulb at a distance of 1 inch from your mouth, and blow air for about three minutes by rotating thermometer very slowly (use blower if required). Note down the thermometer reading after every one minute (do not keep the thermometer aside while noting down the temperature reading).
4. Wet the thermometer bulb covered with paper napkin or cotton, just by dipping it in water for few seconds (as shown in Fig I). Note down the thermometer reading:_____ **˚C**.
5. Blow air at the cotton or paper napkin on thermometer bulb holding it in a hand and keeping it at a distance of 1 inch from your mouth for about three minutes by rotating thermometer very slowly (use blower if required). Note down the thermometer reading after every one minute (do not keep the thermometer aside while noting down the temperature reading).

Observations: For Step 3 and 5

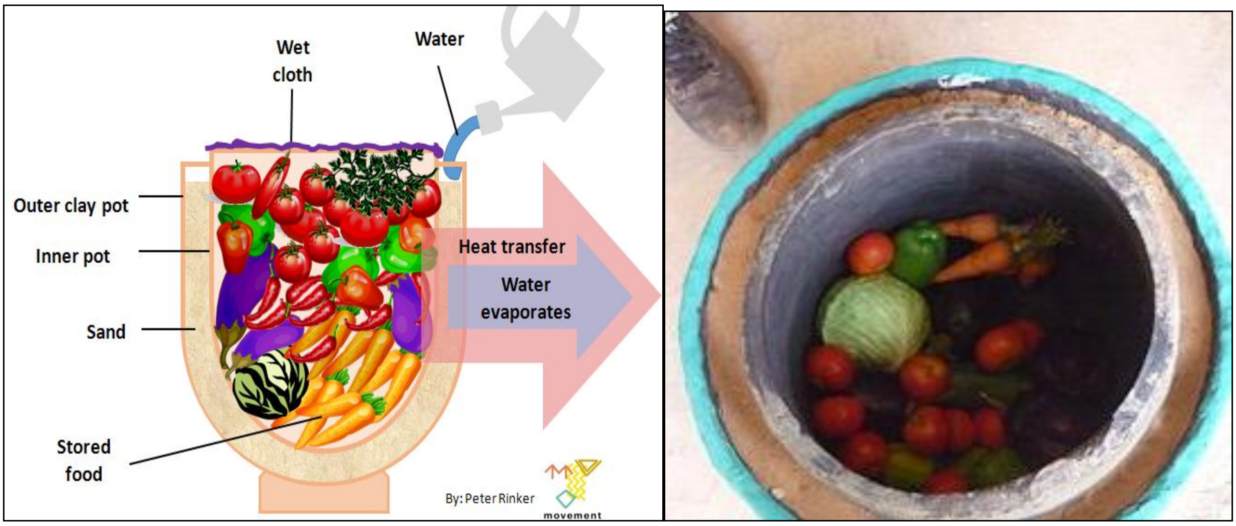
		Thermometer reading in ˚C		
		After 1 min.	After 2 min	After 3 min
Step 3	Bulb covered with dry paper napkin or cotton			
Step 5	Bulb covered with wet paper napkin or cotton			

Q 14. How did the temperature change in two cases? Can you explain it?

If the students have done it correctly, then they should see an increase in temperature reading on thermometer when air was blown on dry cotton/paper napkin because of hot air coming from mouth. The temperature reading should drop when blown on a wet cotton/paper napkin. If the student has kept the thermometer very far from mouth they may not observe a change in temperature in Step 3.
This gives an evidence of evaporative cooling. Please note that if ambient temperature is above 37°C (temperature of human body), you may not see heating in Step 3.

Q 15. In summer days if electricity is cut off for two days, then how can you keep food cool (to prevent its spoilage) without a refrigerator?

Students may suggest different ideas here. You may give them example of different systems utilizing evaporative cooling to preserve food items.



A traditional Indian porous clay container, Matka /Matki used for storing food and cooling water and other liquids. Source: https://en.wikipedia.org/wiki/Pot-in-pot_refrigerator.

Evaporative coolers, which can cool a big hall by simply blowing dry air over a filter wet with water. Source: https://en.wikipedia.org/wiki/Evaporative_cooler

Q 16. Suppose you have to walk outside on a hot sunny day, how can you maintain your body temperature and protect yourself from sun stroke by utilizing the phenomena of evaporation?

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> Here students may suggest using a wet cloth or handkerchief which can provide evaporative cooling. (Variable answers expected from the students)
> They may also mention/I will drink lots of water. Cover my head by cap. Keep myself covered. Splash water on my body frequently. Eat fruits. Cover myself with moist cloth. Use umbrella. It might be worth discussing how the steps they have suggested are related to evaporative cooling.

Task 3: Faster and Slower Evaporation

Q17. Following situations involve evaporation of a liquid. In which case we want the evaporation to happen fast and in which case we want it to happen slowly:

(a) Drying of clothes

(b) Drying of papads

(c) Evaporation of water in a lake

(d) Evaporation of water in puddles after rains

(e) Drying of soil in an agricultural field

(f) A perfume sprayed on a handkerchief

(g) Drying of Nail polish on nails

(h) Paint done on a wall

(i) Fresh plaster on a wall

Above cases show that in some situations we want evaporation be as fast as possible and in some situations, we want to slow down the evaporation.

Q18. How can you make the evaporation in any situation slower or faster?

> By increasing surface area and flow of air, sometimes by applying heat to the system. Sometimes changing the liquid makes the evaporation in a situation faster. Some liquids evaporate faster than others because they are more volatile than others. The force of attraction between their molecules is less than others; so they require less heat to overcome this force of attraction between the molecules.

Q19. Arrange the following in increasing order of evaporation rate.
Water, spirit, kerosene, coconut oil.

> Coconut Oil < Water < Kerosene < Spirit

Now we will study evaporation of different liquids at the same conditions of temperature and pressure.

What we need: Stop Watch or a clock, four droppers, acetone (2 mL), ethanol/spirit (2 mL), glycerine (2 mL), water (2 mL), brown paper or any other absorbing paper (4 pieces of about 4 cm × 2 cm size).

Procedure:
1) You are given four small containers labelled 1, 2, 3, 4 containing acetone, alcohol, glycerine and water, respectively.
2) On four pieces of brown paper, write on corner the names of four liquids.
3) Using a dropper, place one drop of each liquid on the piece of brown paper having its name.
4) Note down the time required for complete evaporation of the liquid on each paper with the help of stop watch.

Observations:
Room temperature: ....˚C

Sr. No.	Liquid	Time (Seconds) required for evaporation of the liquid
1	Acetone	
2	Ethyl Alcohol	
3	Glycerine	
4	Water	

Q 20. Which of the above four liquids evaporates faster? Can you explain why?

> Usually the order of evaporation rate is:
> Acetone > Ethyl Alcohol > Water > Glycerine
> Can student relate to higher or lower intermolecular forces in different liquids?

Q 21. If you were to make a paint, which of the above liquids would you choose to mix the solid colour in? Why would you chose that liquid?

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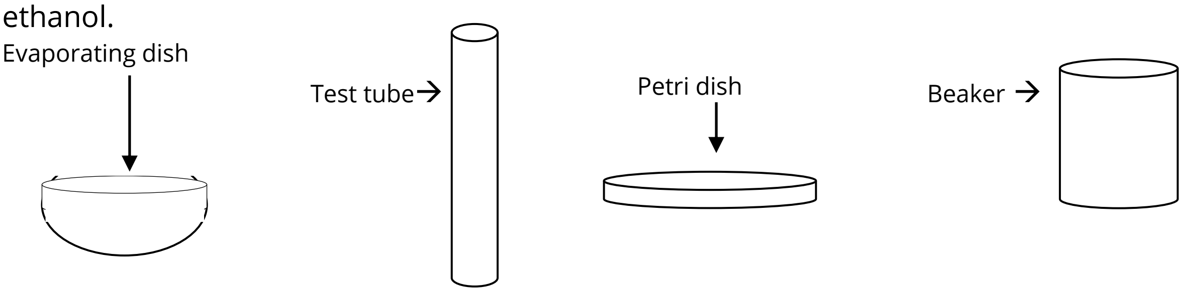
> For paints, we want a solvent which dries very fast, but we don't want it to dry so fast that the paint dries in your painting brush itself. Therefore, some liquid with intermediate rate of evaporation is better for making paints.

Q 22. 10 mL of ethanol if placed in different containers, like evaporating dish, test tube, petri dish, beaker. Arrange the containers in the increasing order of evaporation rate of ethanol.



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> Test Tube < Beaker < Evaporating dish < Petri dish. Since the volume of liquid taken is same in all cases; evaporation is directly proportional to the surface area.

Q 23. Can Evaporation be a source of pollution? If yes, give some examples and explain.

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> Here, you may discuss the example of solvents used in different kinds of paints, all of which evaporate and become a part of atmosphere causing air pollution. You may check which solvents are used in manufacturing paints.
>
> Solvents used in Insecticides spray, Body spray, furniture polish; Liquid chemical spillage during transportation, Refineries, Petrol/Diesel pump, Ration shops where Kerosene is stored, Industrial Chemical laboratories, School and Colleges Chemistry laboratories, Chemical storage hubs etc. can be discussed.

Q 24. Explain the statement of Leonardo da Vinci given in the beginning of the Learning Unit.

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> **Suggestions for further extension:**
> Crystallization is one process in which rate of evaporation is very crucial. For obtaining larger crystals from a saturated solution, usually we want the evaporation to be slow.

Try preparing a saturated salt solution. Keep this in 4 different beakers in four different places with some of these covered and some uncovered. See how changes in rate of evaporation affects the size and nature of crystals formed.

These tasks can help students to become aware that even before modern scientific understanding was familiar to the common people, applications based on evaporation theory were used in a day to day life.

Some scientific discoveries enhanced our understanding of evaporation include

1) In 16th century Leonardo da Vinci invented hygrometer to find out humidity. This invention was helpful in relating evaporation to humidity and also helpful in preparing equipment based on the principle of evaporation. He also made water-based air cooler.
2) In 18th century, John Dalton studied evaporation and its importance to global cycle. He showed that water vapour in air is not chemically combined with other gases and also established rate of evaporation to humidity in the air.

Suggested Readings:

1) V. Bar & I. Galili (1994) Stages of children's views about evaporation, International Journal of Science Education, 16:2, 157-174, DOI: 10.1080/0950069940160205.
2) Russell Tytler (2000) A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: dimensions of conceptual progression, International Journal of Science Education, 22:5, 447-467, DOI: 10.1080/095006900289723.

References:

1) Lohner, Science Buddies, Sevenja. (https://www.sciencebuddies.org, search for Evaporation)
2) Evaporation and Evapotranspiration , Measurements and Estimation by Abtew, Wossenu, Melesse, Assefa M.
3) Droplet Wetting and Evaporation , e book,,Ist ed. Edited by David Brutin