

The Principles of Chemistry



Dmitri Mendeleev · 1903

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From the original: Д. И. Менделеев, Основы химии, 7-е изд. (С.-Петербург, 1903)

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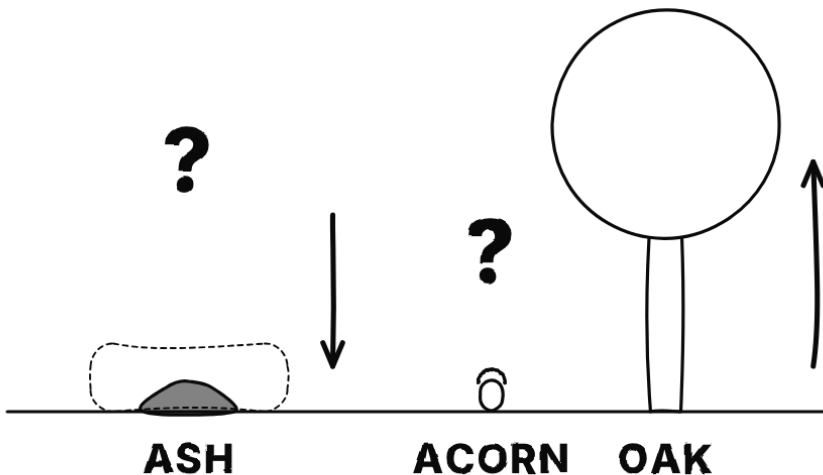
What Holds Substances Together

A Window of Temperature

Halfway Apart

Nothing Disappears

Picture a log burning in a fireplace on a winter evening. An hour later a heavy piece of wood has turned into a small grey heap of ash that you could hold in one hand. Now picture an acorn, lighter than a coin, that over a lifetime becomes an oak weighing many tonnes. In the first case matter seems to vanish, and in the second it seems to appear out of nothing. For centuries people who watched these scenes drew exactly that conclusion, and Mendeleev opens his great textbook by showing why they were wrong.



Matter Seems to Come and Go

He begins by saying what chemistry is about. Physics had already learned to describe gravity, heat, light and electricity, but there was something else at work inside every piece of matter. Hidden forces, quiet in ordinary life, wake up when one substance turns into another. Chemistry, in his words, studies the uniform substances from which every body in the world is built, how they turn into one another, and what happens while they do. Such a change is called a chemical reaction, and it takes place only when the substances touch as closely as possible, down to their smallest invisible particles, the molecules.

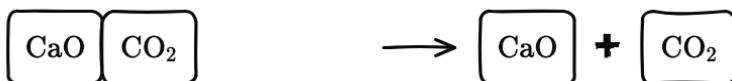
Mendeleev then sorts reactions into three main kinds. The first is combination, where two substances become one. Heat iron filings together with sulphur, and you get a new substance, iron sulphide. Before heating you could pull the iron out with a magnet and leave the sulphur behind; afterwards no magnet and no microscope can find the two apart. Combinations usually give off heat, and ordinary burning is one of them: the fuel joins with a part of the air called oxygen. The gas flame under your kettle is exactly this kind of reaction, gas combining with oxygen and releasing the heat that boils the water.

COMBINE



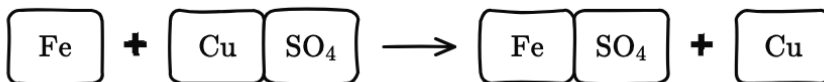
HEAT OUT

SPLIT



HEAT IN

SWAP



Three Kinds of Reaction

The second kind is decomposition, the reverse: one substance falls apart into several. Heat wood without air, and it gives a burning gas, a watery liquid, tar and charcoal; factories once made lighting gas and charcoal this way on a large scale. Heat chalk, limestone or marble strongly, and they leave behind lime while releasing a gas, carbon dioxide. Where combination usually gives off heat, decomposition usually swallows it. The baking powder in a cake works in a similar way: warmed in the oven, it decomposes and releases carbon dioxide, which lifts the dough.

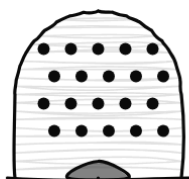
The third kind is a swap, where two substances meet and two new ones come out. Dip an iron nail into a blue solution of copper sulphate, and the nail soon wears a coat of red copper, while the

solution slowly turns green, because iron has taken the place of copper. Mendeleev calls this substitution, or double decomposition, and notes that this is how iron is coated with copper and copper with silver. The silver plating on a cheap spoon or the copper layer on a circuit board in a factory relies on the same idea of one metal taking another's place.

Why did a science of these changes arrive so late, when people had used them for thousands of years? Mendeleev gives two reasons. First, most real processes, in nature and in industry, are tangles of many combinations, decompositions and swaps happening at once. Second, and more important, many reactions involve gases, above all the air, and gases are invisible. Only in the sixteenth and seventeenth centuries did people grasp that air and other gases have weight. Until then, the gases slipped through every account, and matter seemed to come and go.

Go back to the burning log. If you could catch all the smoke and weigh it, you would find that the gases weigh more than the wood did, because the wood has combined with part of the air. The acorn grows into an oak by taking gases from the air and water with dissolved substances from the soil. Water that dries from wet laundry is not lost either; it returns as rain, dew and snow. Matter only changes its place and its form; it is never created and never destroyed.

ASH + GASES



LAVOISIER

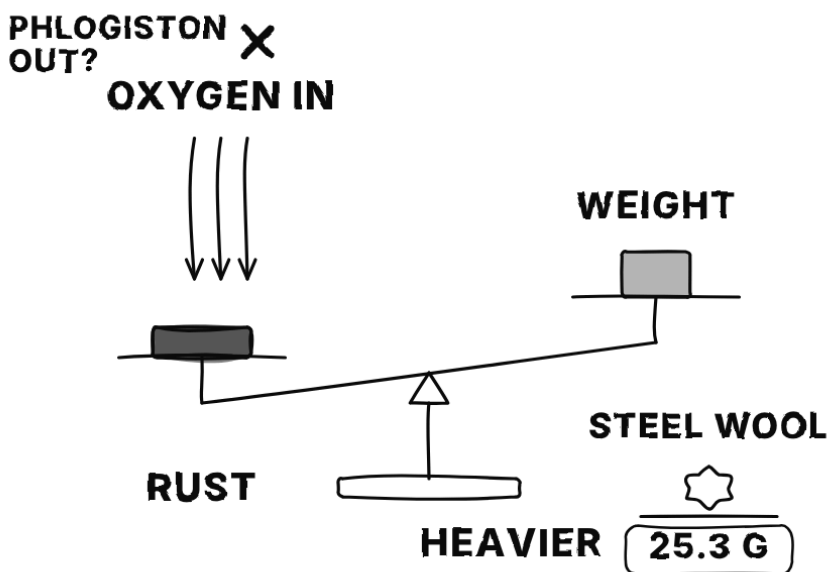
WEIGHTS

BEFORE = AFTER

Lavoisier Weighs Everything

This truth was settled by the French chemist Antoine Lavoisier in the second half of the eighteenth century, and his tool was the balance. He weighed every substance he started with, and even the vessels, and then weighed everything that came out. Every time, the total weight after the reaction equalled the total weight before. That is the law of conservation of matter, and Mendeleev insists that a student of chemistry must make it their own before going on. It also gives every reaction an equation: what goes in must equal what comes out, so if one weight is unknown, it can be found from the others, and if the sums do not match, something has been missed. A kitchen scale is enough to feel the idea: whatever you mix in a sealed jar, the jar weighs the same afterwards.

Mendeleev's first example is rust. Iron rusting in damp air, or iron heated until it is covered with dark scale, becomes heavier, not lighter. The extra weight comes from oxygen in the air: in a vacuum, or in hydrogen or nitrogen, iron neither rusts nor forms scale. So the scale is more complex than the iron; it is a combination. Before Lavoisier, people saw it the other way round, as if something had left the iron, an imagined substance they called phlogiston. The balance shows that something has joined the iron, not left it.



Rusting Iron Gets Heavier

This part leaves out the details of Mendeleev's examples and the history of the old phlogiston idea, which come next.

Try it yourself

Put a piece of steel wool on a kitchen scale that reads tenths of a gram, and note its weight. Wet it lightly, let it stand for a few days until it turns orange with rust, then dry it well and weigh it again. It will be slightly heavier, not lighter, because the iron has combined with oxygen from the air.

Remember

Chemistry studies how substances turn into one another, through reactions between their tiniest particles. There are three main kinds of reaction: combination, decomposition, and the swap in which one substance takes another's place. Chemistry came late because so many reactions involve invisible gases, which people did not weigh. Lavoisier, weighing everything before and after, showed that the total weight never changes: matter is neither created nor destroyed. That is why rusting iron gets heavier: it has taken oxygen from the air.

Questions

1. Why did people long believe that burning wood destroys matter?
 - a. Because the ash really weighs less than the original wood plus the air it used

- b. Because the gases that leave in the smoke are invisible and were never weighed
 - c. Because fire turns part of the wood into heat, which has no weight
 - d. Because wood is a mixture, and mixtures lose weight when they are heated
2. An iron nail is left in damp air until it rusts. What does the balance show, and why?
- a. It is lighter, because rust is the iron with something taken out of it
 - b. It weighs the same, because matter is neither created nor destroyed
 - c. It is heavier, because the iron has combined with oxygen from the air
 - d. It is lighter, because some of the iron has crumbled away as dust
3. Heated iron filings and sulphur become a substance no magnet can separate. Which kind of reaction is this?
- a. Combination, because two substances have become one new substance
 - b. Decomposition, because the heat breaks the iron down into smaller pieces
 - c. Substitution, because sulphur takes the place of the iron
 - d. No reaction at all, because the two are only mixed very finely
4. If the weights before and after an experiment do not add up to the same total, what should a chemist conclude?

- a. That some matter really was destroyed in the reaction
- b. That a substance taking part, often a gas, has been left out of the count
- c. That the reaction gave off heat, which carried weight away
- d. That the law holds only for reactions between solids

Answers

- 1. **b)** The wood combines with part of the air and leaves as invisible gases; caught and weighed, those gases weigh more than the wood did.
- 2. **c)** Rusting is a combination: the iron takes oxygen from the air, so the rust weighs more than the iron alone.
- 3. **a)** After heating, the two have joined into iron sulphide, one new substance in which neither can be found apart.
- 4. **b)** Since matter is never created or destroyed, sums that do not match mean something has been missed.

Worked examples

Finding a missing weight A piece of iron weighing 56 grams is heated in air until it is completely covered with scale, and the whole piece now weighs 72 grams. How much of the air took part in the reaction?

Matter is neither created nor destroyed, so the weight of what goes in equals the weight of what comes out.

What went in is the iron plus the part of the air that joined it; what came out is the scaled iron.

So the air that joined the iron weighs the difference: 72 grams minus 56 grams.

That gives 16 grams, all of it oxygen taken from the air.

Answer: 16 grams of oxygen

Practice

1. A seed weighing less than a gram grows into a tree weighing several tonnes. Using the law of conservation of matter, explain where the tree's weight came from.

Hint: Ask what the plant takes in from its surroundings, both above and below the ground.

Answer: The weight was not created. The tree takes gases from the air through its leaves and water with dissolved substances from the soil through its roots, and builds its body out of them. In a gas without the nourishing part of the air, the plant does not grow but dies.

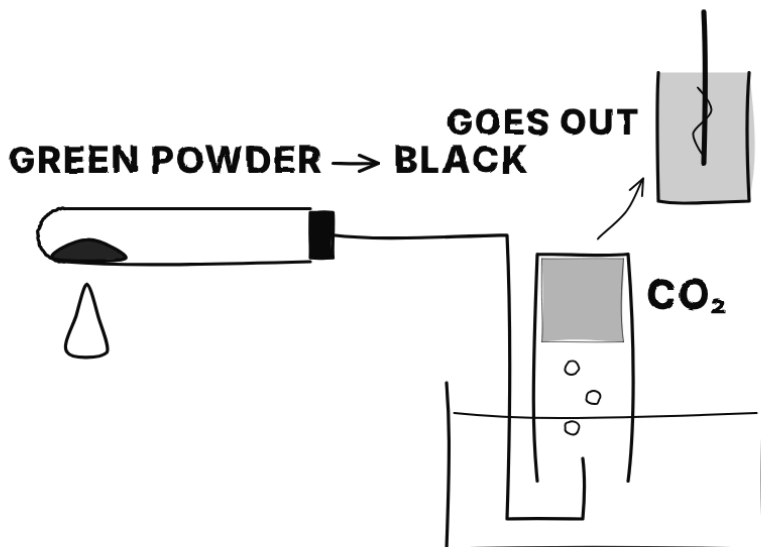
2. An iron nail is placed in a blue solution of copper sulphate. It soon becomes coated with copper and the solution turns green. Which kind of reaction is this, and why is it not a simple combination?

Hint: Count how many substances go in and how many come out.

Answer: It is a substitution, or swap: two substances go in, iron and copper sulphate, and two come out, copper and iron sulphate. Iron has taken the place of copper, so it is not one substance made from two.

Gases You Cannot See

Take a spoonful of a bright green powder, the same stuff that gives the green stone malachite its colour, and heat it in a glass tube. Before your eyes it turns black. Weigh the black powder, and it is lighter than the green powder was. By the law we met in the first part, nothing can simply vanish, so something must have left the tube. But nothing seems to come out: no smoke, no flame, nothing to see.

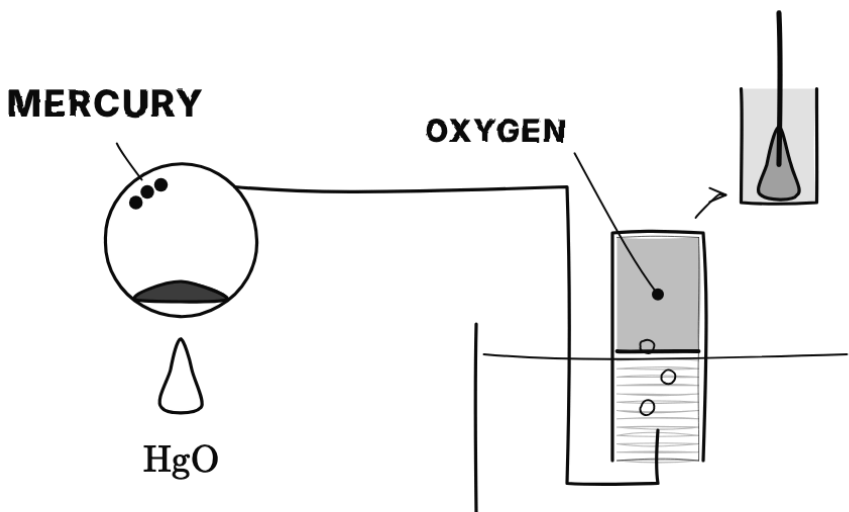


Catching the Hidden Gas

Mendeleev shows how to catch it. Close the tube with a tight cork, run a thin pipe from the cork down into a bowl of water, and heat again.

Now bubbles rise through the water. The green powder, copper carbonate, is splitting into black copper oxide and a gas, carbon dioxide, as clear and colourless as air. Lower a burning splinter into this gas and it goes out as if dipped in water. And when the black powder and the gas are both weighed, together they weigh exactly as much as the green powder did. Without the balance, Mendeleev says, it would have been easy to miss the gas altogether. The fizz in a bottle of sparkling water is this same gas, and a fire extinguisher at a factory uses it for the same reason the splinter goes out.

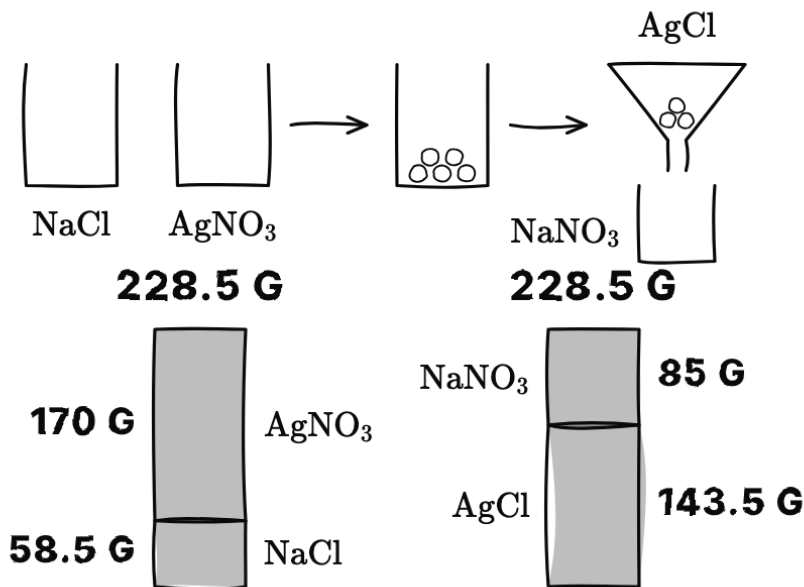
His next example is the experiment that mattered most in Lavoisier's day. A red powder, mercury oxide, the scale that forms when mercury is heated in air, is heated in a glass vessel joined by a pipe to a bath of water. Over the end of the pipe stands a glass cylinder, filled with water and turned upside down, so that every bubble that comes out rises into it and pushes the water down. This is how chemists collect a gas. As the red powder is heated, shiny drops of metallic mercury gather on the cool glass, and a gas bubbles into the cylinder. Hold a glowing splinter in that gas, one that would simply die in ordinary air, and it bursts into bright flame. This gas is oxygen, the very part of the air that keeps us breathing, makes fuels burn, and turns metals into rust and scale. So the red powder has decomposed into two things, mercury and oxygen.



Mercury Oxide Gives Up Oxygen

A third experiment shows a swap, and this time with numbers. Dissolve common salt in water, and dissolve silver nitrate, which was once used to cauterise wounds, in another glass. Pour the two clear solutions together, and at once a white powder appears and sinks to the bottom. Pour the cloudy liquid through a paper filter: the white powder, silver chloride, stays on the paper, and the clear liquid that runs through holds a new dissolved salt, sodium nitrate. Mendeleev gives the weights: fifty-eight and a half grams of salt and one hundred and seventy grams of silver nitrate give one hundred and forty-three and a half grams of silver chloride and eighty-five grams of sodium nitrate. Both sides add up to the same two hundred and twenty-eight and a half grams, just as the law demands. A coffee filter in your

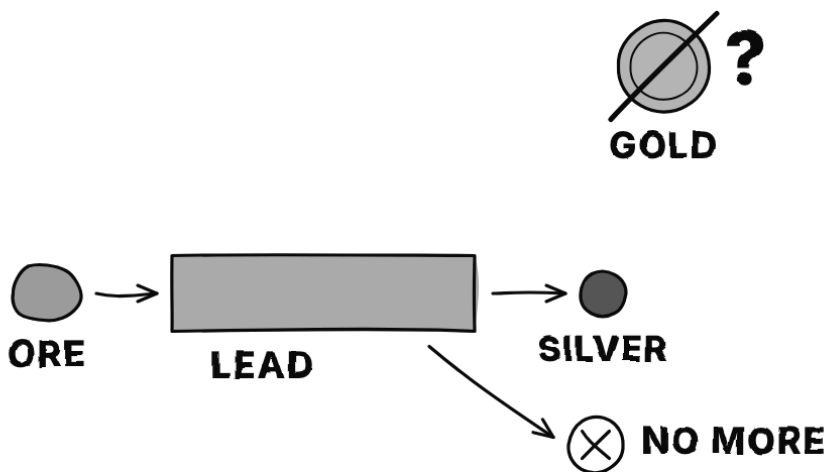
kitchen does the same job as Mendeleev's paper cone: it lets the liquid pass and keeps the solid behind.



A Swap That Still Adds Up

Once the amount of matter is known to be fixed, Mendeleev asks a deeper question. Can any substance be turned into any other, without limit, or is there a boundary? This is the question of the kind of matter, not its quantity, and it is harder. Everyday life gives mixed hints: plants build countless substances from air and soil, and iron can be turned into ink or blue paint, yet nobody has ever made bread from stone or gold from copper. The ancient answer, set out in Greece by Empedocles, was that everything is made of four elements: air, water, earth and fire. It was not drawn from measurement; it simply

named the three states of gas, liquid and solid, and the fire that changes them.

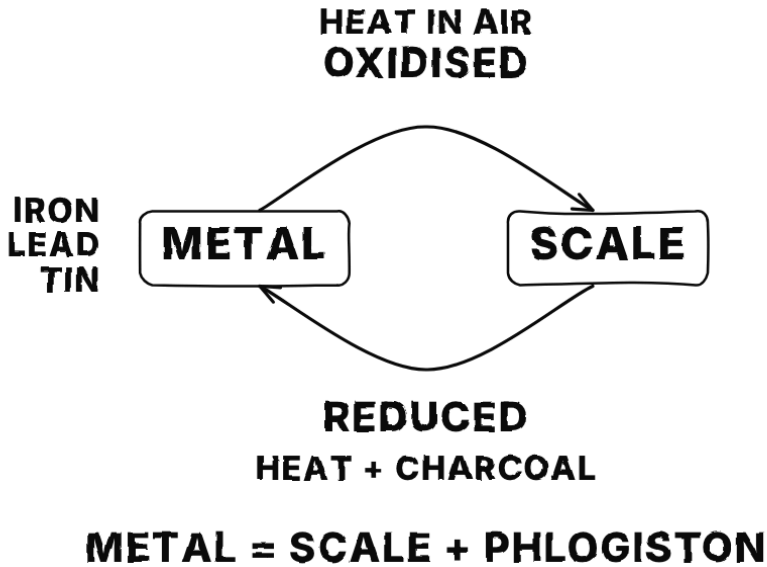


The Silver Was Already There

The alchemists, who learned their art from Arab scholars and brought it into Europe through Spain, chose the other answer: transformation without end. They searched for a philosopher's stone that would turn everything into gold and make old bodies young. Mendeleev is fair to them: their mistake was natural. From a shiny grey ore they got lead, and from lead they got silver, so it looked as if metals could be ennobled step by step, and gold must be next. Had they weighed carefully, they would have seen that the silver had been in the lead all along, as a small share, and that once taken out, no further work would draw more silver from it. Their gift to chemistry was a

mountain of experiments; their failure was that they rarely weighed and never asked simple, clear questions. It is the same lesson as a refinery today: the precious metal is extracted from an ore that already contains it, never made from a cheaper one.

Two changes interested the alchemists most. When a metal rusts, or turns into scale in a fire, it is oxidised; when the metal is won back from that earthy powder, it is reduced. Iron, lead and tin all scale when heated in air and come back as metal when heated with charcoal, and this is how metals are smelted from their ores. The first theory to explain both came from Becher and above all from Georg Stahl, physician to the King of Prussia, in seventeen twenty-three. Every burnable body, Stahl said, contains an invisible fire substance, phlogiston. A metal is scale plus phlogiston: when it burns or rusts it gives phlogiston off, and charcoal, rich in phlogiston, gives it back. The idea was beautifully simple, and it won many followers.



Rusting and Smelting, Two Ways

This part has left out how gases are collected step by step and the finer history of alchemy; the next part puts Stahl's idea on the balance.

Remember

Many reactions give off or take up gases that cannot be seen, and only weighing reveals them. Green copper carbonate splits into black copper oxide and carbon dioxide, and red mercury oxide into mercury and oxygen. When salt and silver nitrate swap partners, the weights on both sides still add up to the same total. The alchemists believed matter could be transformed without limit, but they did not weigh, and their silver had been in the lead all along. Stahl explained rusting and smelting by an invisible fire substance, phlogiston, given off when a metal burns and taken back from charcoal.

Questions

1. Heated green copper carbonate leaves a black powder that weighs less. Why is this not a loss of matter?
 - a. Because the missing weight leaves as a colourless gas, carbon dioxide, which can be caught and weighed
 - b. Because heat makes the black powder denser, so it only seems lighter on the balance
 - c. Because the missing weight turns into the heat that the flame gives to the tube
 - d. Because some of the copper evaporates and settles on the cool glass as metal

2. How can the gas from heated mercury oxide be told apart from ordinary air?
 - a. It puts out a burning splinter, as if the splinter were dipped in water
 - b. It makes a glowing splinter, which would die in air, burst into bright flame
 - c. It is heavier than water, so it stays at the bottom of the cylinder
 - d. It turns the water in the bath green as it bubbles through
3. Why did the alchemists believe lead could be turned into silver?
 - a. Because they weighed the silver and found it heavier than the lead
 - b. Because they could turn silver back into lead whenever they wished
 - c. Because they got silver out of lead and did not weigh, so they missed that it had been there all along
 - d. Because the four-element theory proved that every metal can become every other
4. In Stahl's theory, why does heating an ore with charcoal give back the metal?
 - a. Because charcoal takes oxygen out of the ore
 - b. Because the heat alone drives the earthy part out of the ore
 - c. Because the metal is hidden inside the charcoal and is set free
 - d. Because charcoal is rich in phlogiston and hands some of it to the ore

Answers

- 1. a)** The green powder splits into black copper oxide and carbon dioxide, and the two together weigh exactly as much as the green powder did.
- 2. b)** The gas is oxygen, which supports burning far more strongly than air, so a glowing splinter flares up in it.
- 3. c)** The silver was a small share already inside the lead; careful weighing would have shown it, and that no more silver comes once it is taken out.
- 4. d)** For Stahl a metal was scale plus phlogiston, so the charcoal, rich in phlogiston, gave it back to the earthy powder.

Worked examples

Salt and silver nitrate on the balance About 58.5 grams of common salt and 170 grams of silver nitrate are dissolved and mixed. They give 143.5 grams of insoluble silver chloride and 85 grams of sodium nitrate. Do the weights obey the law of conservation of matter?

The law says the total weight of what goes in must equal the total weight of what comes out; the water only helps the substances move and is not counted.

What goes in: 58.5 grams of salt plus 170 grams of silver nitrate makes 228.5 grams.

What comes out: 143.5 grams of silver chloride plus 85 grams of sodium nitrate also makes 228.5 grams.

The two totals are equal, so no matter appeared or vanished in the swap.

Answer: Yes: 228.5 grams on both sides

Practice

1. In the same experiment someone dries and weighs only the silver chloride, 143.5 grams, and the starting substances, 58.5 grams of salt and 170 grams of silver nitrate. How much sodium nitrate must they find when they evaporate the clear liquid?

Hint: The total after the reaction must equal the total before it.

Answer: 85 grams. Before: 58.5 plus 170 is 228.5 grams; after, the silver chloride takes 143.5 grams, so the sodium nitrate is 228.5 minus 143.5, which is 85 grams.

2. Mercury oxide is heated, and the red powder slowly disappears, leaving only some shiny drops of mercury. A friend says part of the substance was destroyed by the heat. How would you answer, and what would you do to prove it?

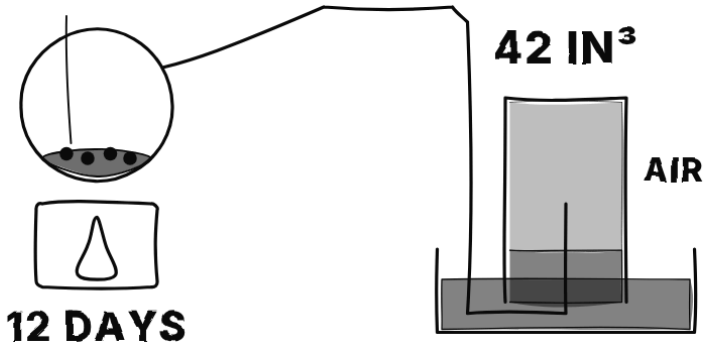
Hint: Think about what might be leaving the vessel unseen, and how to catch it.

Answer: Nothing was destroyed: the red powder decomposes into mercury and oxygen, a colourless gas. Lead a pipe from the vessel into water and collect the bubbles in an upturned cylinder; a glowing splinter flares up in the gas, and the mercury and the gas together weigh as much as the red powder did.

Twelve Days with Mercury

Imagine a glass flask with a long bent neck, its belly holding a little pool of mercury. The neck curves down and rises again under a glass bell standing in a dish of mercury, so that a fixed amount of air is shut in, cut off from the room. A small furnace keeps the flask almost hot enough to boil the mercury, day and night, for twelve days. This is the experiment Antoine Lavoisier made in seventeen seventy-four, and it decided between two pictures of burning.

RED SCALE

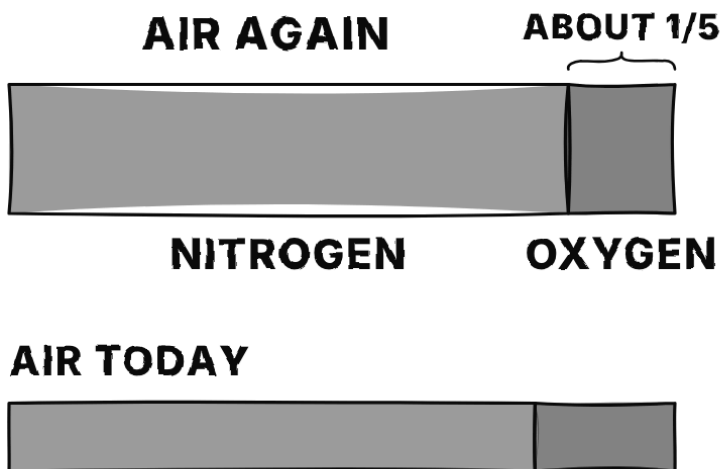


Twelve Days of Heating

The question was sharp. According to Stahl's theory from the last part, a metal turning into scale gives phlogiston off into the air, so the air in the bell should gain something, or at least not lose. Lavoisier thought the opposite: the metal takes something out of the air. So the whole experiment turns on one measurement, the amount of air before and after. Lavoisier measured the volume of the flask, the volume of the mercury, the air under the bell, and even the temperature and pressure, so that he knew exactly how much air was shut in.

As the days passed, red flakes grew on the surface of the mercury: the same red mercury oxide we watched decompose in the last part. When the apparatus had cooled, the air under the bell had shrunk. Of fifty cubic inches of air, only forty-two were left. And the weight the air had lost was exactly the weight the mercury had gained. So nothing had been given off into the air; a part of the air had joined the mercury.

The air left in the bell was strange. It would not turn any metal into scale, and it supported neither burning nor breathing. A lit splinter plunged into it went out at once, in Lavoisier's own words, as if it had been dipped into water. This leftover gas is nitrogen; the part that joined the mercury is oxygen, which, as we saw, can be driven out of the red flakes again. Mix the two back together, and you have ordinary air once more. So air is not a single element at all, as the old four-element picture held: it is a mixture of two gases. The air you breathe at your kitchen window is mostly nitrogen, with about a fifth oxygen, which is roughly the share Lavoisier saw vanish under the bell.

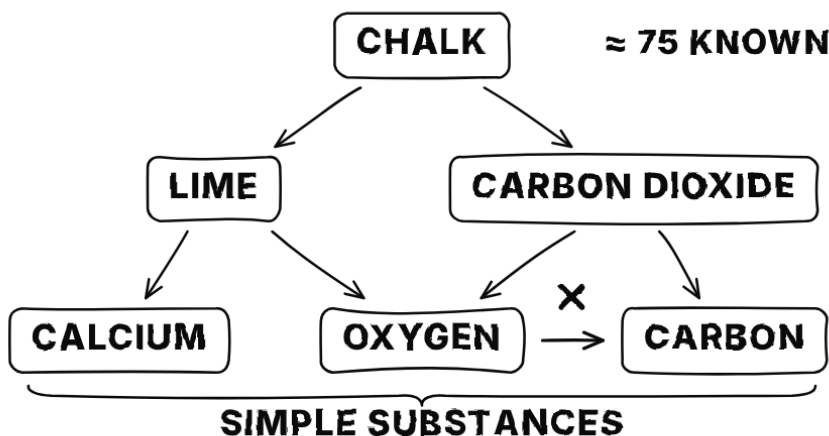


Air Is Two Gases

The whole of Stahl's picture now turns inside out. Burning and rusting do not release anything; they take oxygen from the air. Scale and rust are not simpler than the metal, they are the metal combined with oxygen. And when charcoal brings a metal back from its scale, the oxygen moves from the scale to the charcoal and forms the very gas that charcoal makes when it burns in air. So that gas, too, is a compound, of carbon and oxygen. Phlogiston was never needed; the balance showed it was never there.

From here Mendeleev follows the idea down to the bottom. Chalk, heated, gives lime and carbon dioxide; lime and that gas, brought together with water, give back a substance like chalk, so chalk is a compound. But carbon dioxide is itself carbon and oxygen, and lime is

a metal called calcium joined with oxygen. Keep taking things apart, and in the end you reach substances that no method at all can split into others or build from others. These Lavoisier called simple substances, and every uniform substance is either simple or compound. In Mendeleev's day about seventy-five were known for certain, and in everyday life we meet the compounds of no more than twenty-five. A modern laboratory or factory works with millions of compounds, yet every one of them is built from about a hundred kinds of simple substance.

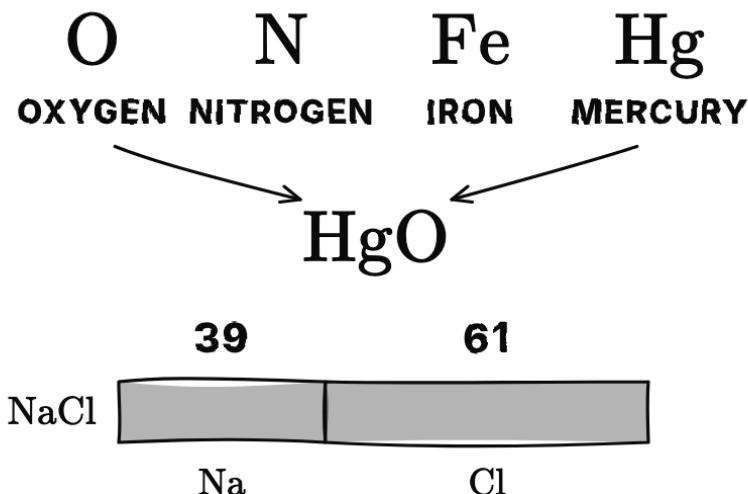


Down to Simple Substances

No simple substance has ever been seen turning into another. That is the end of the alchemists' dream: one metal cannot be made from another. Put this together with the law that matter is never created or

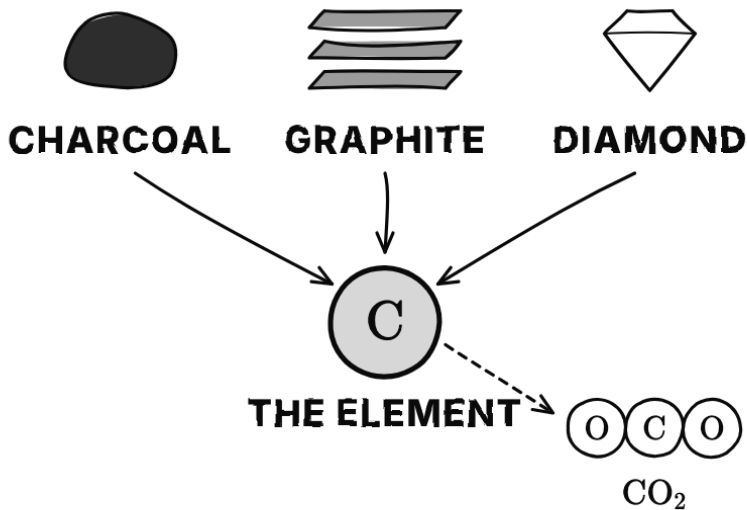
destroyed, and something sharper follows. In every reaction, the amount of each simple substance stays the same, before and after. Chemistry becomes the study of what each simple substance is joined to, and how, before and after a change.

To write this down, chemists gave every simple substance a short sign, one or two letters of its Latin name: O for oxygen, N for nitrogen, Fe for iron, Hg for mercury. A compound is written by setting the signs side by side, so red mercury oxide is HgO. Each sign also stands for a fixed relative weight, the weight of an atom, so a formula tells not only what a substance is made of but how much of each. Common salt, for instance, works out to about thirty-nine parts sodium and sixty-one parts chlorine in every hundred by weight. And in every reaction written with these signs, each simple substance must weigh the same on both sides. A recipe card in the kitchen does the same job: it lists the ingredients and, from their amounts, how much of each ends up in the cake.



Signs, Formulas, Weights

Last comes a fine but deep distinction. Red mercury oxide does not contain shiny liquid mercury, nor does it contain oxygen gas. It contains the stuff of those two, which Mendeleev calls the elements mercury and oxygen, the way steam contains the stuff of ice but not the ice itself, or bread contains the stuff of grain but not the grain. A simple substance is a real thing you can hold; an element is what persists through all its compounds and forms. Carbon shows this best: charcoal, graphite and diamond are three quite different simple substances, but there is only one element, carbon, and in carbon dioxide there is no charcoal, no graphite and no diamond, only carbon. Fluorine was recognised as an element from its compounds long before anyone had the gas itself in hand.



One Element, Many Forms

This part leaves out the details of Lavoisier's measurements and the weights of the atoms, which the book sets out in its tables.

Remember

Lavoisier heated mercury in a closed volume of air for twelve days and found the air had shrunk, its lost weight equal to the mercury's gain. Burning and rusting take oxygen from the air; they release no phlogiston, and air is a mixture of oxygen and nitrogen. Taking substances apart ends at simple substances, which cannot be split or turned into one another. So in every reaction the amount of each simple substance stays the same, which is what chemical signs and formulas let us write down. An element is the stuff that persists through a substance's compounds and forms, like carbon in charcoal, graphite, diamond and carbon dioxide alike.

Questions

1. Why did the shrinking of the air under the bell count against Stahl's phlogiston theory?
 - a. Because phlogiston should have been given off into the air, so the air should not have lost anything
 - b. Because the heat of the furnace should have destroyed the phlogiston and left the air unchanged
 - c. Because phlogiston is heavier than air and should have sunk into the mercury
 - d. Because the theory said mercury cannot turn into scale at all
2. What did Lavoisier's experiment show about the air itself?

- a. That air is a single element that metals slowly absorb
 - b. That air is a mixture: oxygen, which joins the mercury, and nitrogen, which supports neither burning nor breathing
 - c. That air turns into nitrogen when it is heated for a long time
 - d. That air contains phlogiston, which the mercury takes up
3. Why can a chemist be sure that a reaction ends with the same amount of iron it started with?
- a. Because iron is a metal, and metals are never used up
 - b. Because iron always stays in the solid that settles at the bottom
 - c. Because iron is a simple substance: it cannot be destroyed, made, or turned into another
 - d. Because the weight of the oxygen always equals the weight of the iron
4. Charcoal, graphite and diamond look nothing alike. In what sense are they one thing?
- a. They are three forms of the same compound of carbon and oxygen
 - b. They are the same simple substance, only of different purity
 - c. They are three compounds that all contain diamond in small amounts
 - d. They are different simple substances, but made of one element, carbon

Answers

1. a) In Stahl's picture the metal gives phlogiston off into the air; instead a part of the air disappeared, and its weight turned up in the mercury.

- 2. b)** One part joined the mercury and could be driven out again as oxygen; the rest, nitrogen, put out a flame, and the two mixed give ordinary air.
- 3. c)** Matter is never created or destroyed, and a simple substance never turns into another, so each one keeps its amount through any reaction.
- 4. d)** A simple substance is a thing you can hold; the element is the stuff that persists through all its forms and compounds, here carbon.

Worked examples

How much of salt is sodium Common salt is written NaCl. The atomic weight of sodium is 23 and that of chlorine is 35.5. What share of salt, by weight, is sodium, and what share is chlorine?

The formula shows one weight of sodium and one of chlorine, so salt is 23 parts sodium to 35.5 parts chlorine.

Together that makes 23 plus 35.5, which is 58.5 parts.

The sodium's share is 23 out of 58.5; times 100, that is about 39.3 per cent.

The chlorine's share is the rest, 35.5 out of 58.5, about 60.7 per cent.

Answer: About 39.3 per cent sodium and 60.7 per cent chlorine

The share of air taken by mercury In Lavoisier's experiment, 50 cubic inches of air were shut in with the mercury, and after twelve days only 42 cubic inches were left. What part of the air joined the mercury?

The air that disappeared joined the mercury as oxygen, so it is the difference between before and after.

50 minus 42 is 8 cubic inches.

As a share of the original air, 8 out of 50 is 16 out of 100.

So about a sixth of the shut-in air went into the red flakes.

Answer: 8 cubic inches, about 16 per cent of the air

Practice

1. Using the same weights, sodium 23 and chlorine 35.5, how many grams of sodium are in 117 grams of common salt?

Hint: First find what part of salt's weight is sodium.

Answer: 46 grams. Salt is 23 parts sodium in every 58.5; 117 grams is two times 58.5, so it holds two times 23, which is 46 grams of sodium.

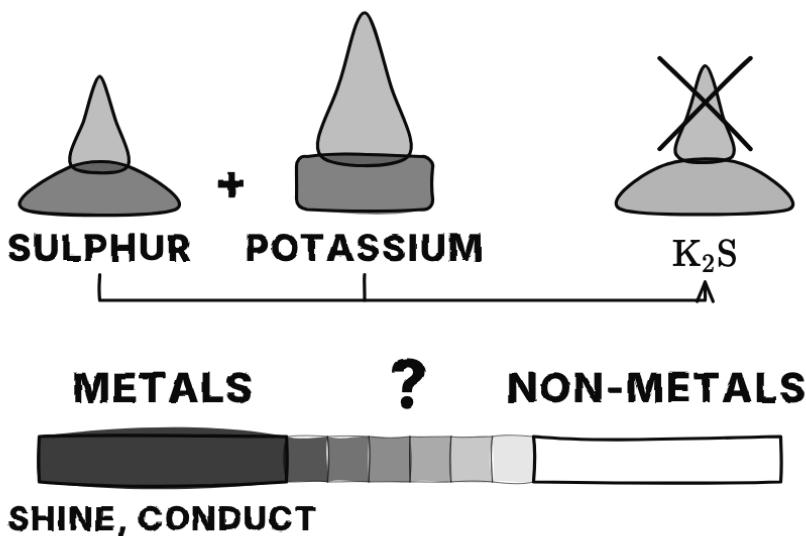
2. Someone says: 'Red mercury oxide contains liquid mercury and oxygen gas, just packed tightly together.' What is wrong with this, and how would Mendeleev put it?

Hint: Think of the difference between a simple substance you can hold and an element.

Answer: The oxide contains neither liquid mercury nor oxygen gas. It contains the elements mercury and oxygen, the stuff of those simple substances, which can be obtained from it again, as steam contains the stuff of ice but not ice itself.

What Holds Substances Together

Light a match and hold it to a small heap of sulphur, and it burns with a blue flame. A piece of potassium, heated, flares up in air even more fiercely. Now let the two combine first, and then try to set fire to the result. It will not burn in air like either of its parts. Something the sulphur and the potassium carried has gone, and Mendeleev wants us to see where.



Two Fires Make No Fire

First he gives a rough map of the simple substances. Many of them shine, let no light through, can be hammered flat, and carry heat and

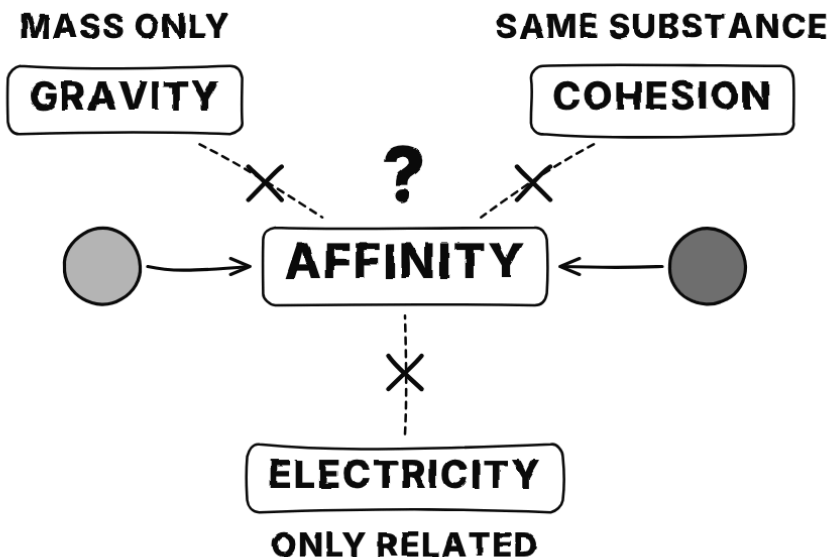
electricity well. These are the metals, and their mixtures with one another are alloys. The others, without these marks, he calls metalloids; today we would say non-metals. In clear cases the two groups are easy to tell apart, but many simple substances sit in between, so the division is useful but not exact.

Around eighty simple substances were recognised when Mendeleev wrote, though half a dozen were so rare that little was known about them. Only a small number make up the common things around us. His list of the most widespread is short: hydrogen in water and living things, carbon in living things, coal and limestone, nitrogen in the air, and oxygen, the most abundant of all, in air, water and rock. Then come sodium in common salt, magnesium in sea water, aluminium in clay, silicon in sand, phosphorus in bones, sulphur in pyrite and gypsum, chlorine in salt, potassium in plant ash, calcium in limestone, and iron in soil, ores and our own blood. A second list holds the substances used in daily life and industry: copper, zinc, silver, tin, lead, gold, platinum and mercury, iodine for medicine, nickel for plating, and others. Look around a kitchen and you can find most of the first list: salt on the table, water in the tap, aluminium foil in a drawer, iron in the frying pan.

Two newer groups end his account. William Ramsay had found a family of gases hidden in small amounts in the air, helium, neon, argon, krypton and xenon, which had never been made to combine with anything. And there was reason to accept the metals radium, polonium and actinium, found in tiny traces in uranium and thorium ores, radium discovered by Marie Curie. Light from distant stars, Mendeleev adds, shows hydrogen, sodium, magnesium and iron there too, so the same simple substances fill the universe. Why some are so plentiful and others so rare, he admits, nobody yet knows. The neon

glow of an old shop sign and the argon inside an ordinary light bulb are those same unsociable gases, put to work.

Now to the real question: what drives substances to combine, and what then holds them together? Each element has its own character. Sulphur combines easily with metals, with oxygen, with chlorine and with carbon; gold and silver combine reluctantly, and many of their compounds fall apart when heated. The cause behind all this Mendeleev calls affinity, or chemical affinity: the same force that pushes substances to react also holds the result together and gives it its strength.



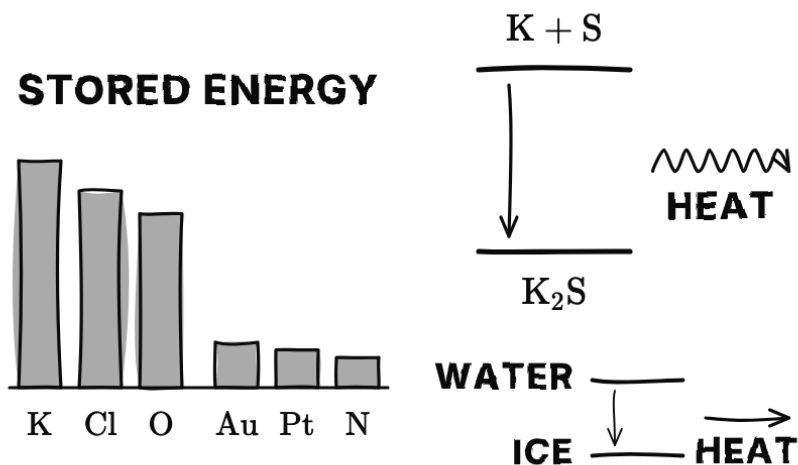
What Affinity Is Not

What is affinity like? Some scientists of the late eighteenth century thought it might be gravity working at very short range. Mendeleev says no: gravity depends only on mass and distance, while affinity depends strongly on what the substances are. It is not the cohesion that holds a crystal or a drop of water together either, because cohesion acts between particles of the same substance, affinity between different ones. Nor is it the stickiness that makes two polished plates cling or water wet glass, because in a chemical change one substance enters into the other and a new one is born. Early in the nineteenth century many identified it with electricity, since reactions produce electric currents and currents can split compounds. But reactions also produce heat, and heat can split compounds too; these links show only that the forces of nature can turn into one another, not that they are the same thing. A battery in your phone is that link at work: a chemical change inside it pushes an electric current through the wires.

The true nature of affinity, Mendeleev admits, is as hidden as the nature of gravity. Yet astronomers predicted the planets very precisely without knowing what gravity is, by applying mechanics. In the same way, he hopes, chemistry can advance by joining its ideas to the well-built theory of heat, without pretending that chemical forces simply are heat. That branch he calls chemical mechanics, and he leaves it for after the reader knows the substances themselves.

Here is the key idea of the part. Since chemical change is movement of tiny particles, and since energy is never lost, only changed in form, every substance must carry a store of chemical energy, an invisible motion that urges it to react. When a reaction gives off heat, part of that store has turned into heat. When a reaction takes heat in, the heat has gone, at least in part, into the store. Potassium, chlorine and

oxygen hold a great deal of it; gold, platinum and nitrogen very little. After several combinations, each giving off heat, the result can become a calm, unreactive compound, though it may still be roused by joining with something energetic.



A Store of Chemical Energy

So back to the potassium and sulphur. Each burns readily on its own, but when they combine, much of their energy leaves as heat, and their compound will not burn in air. It is like melting and freezing: water takes in heat to melt and gives it back when it freezes, and in the same way every combination, decomposition or swap changes the store of chemical energy, with heat given off or taken in. A hand warmer on a winter walk works this way: iron powder combining with oxygen releases its stored energy as steady heat.

This part leaves out the long tables of the rarer simple substances and the finer arguments about the nature of affinity.

Remember

Simple substances divide roughly into metals, which shine, bend and conduct, and non-metals, but the line between them is blurred. About eighty were known in Mendeleev's day, yet only a handful make up most of the earth, the air and living things. Affinity is the force that drives substances to combine and holds them together; it is not gravity, cohesion or electricity. Every substance carries a store of chemical energy, which a reaction partly releases as heat or partly fills up by taking heat in. That is why potassium and sulphur, fierce on their own, form a compound that will not burn.

Questions

1. Why does the compound of potassium and sulphur not burn in air, though each part burns on its own?
 - a. Because sulphur covers the potassium and keeps the air away from it
 - b. Because much of their chemical energy already left as heat when they combined
 - c. Because a compound can never react with oxygen again
 - d. Because the compound is a metalloid, and metalloids do not burn

2. Why can't chemical affinity simply be gravity acting at very short range?
 - a. Because gravity acts only between metals and affinity between all substances
 - b. Because gravity is far stronger than affinity at small distances
 - c. Because gravity depends only on mass and distance, while affinity depends on what the substances are
 - d. Because gravity was not yet understood when affinity was discovered
3. A reaction takes in heat from its surroundings. In Mendeleev's picture, where does that heat go?
 - a. At least in part into the store of chemical energy of the substances formed
 - b. It is destroyed, since the reaction needs it to happen
 - c. It becomes the weight of the new substances
 - d. It is turned into electricity that leaves through the vessel
4. Why does Mendeleev say the division into metals and non-metals is useful but not exact?
 - a. Because a metal turns into a non-metal when it is heated
 - b. Because only a few simple substances are metals at all
 - c. Because metals and non-metals can be changed into one another
 - d. Because clear cases are easy, but many simple substances sit in between

Answers

1. **b)** Part of the energy of potassium and sulphur was released as heat when they joined, so the compound has too little left to burn like its parts.
2. **c)** Affinity depends strongly on the kind of matter, which gravity ignores entirely.
3. **a)** Energy is never lost, only changed in form, so heat taken in goes, at least partly, into the chemical energy store.
4. **d)** The marks of a metal are clear in sharp examples, but many simple substances share only some of them.

Practice

1. Reactions produce electric currents, and electric currents can split compounds. Why, then, did Mendeleev refuse to say that chemical forces are simply electrical forces?

Hint: Ask whether heat has the same two links with chemistry.

Answer: Heat is linked to chemistry in exactly the same way: reactions give off heat, and heat can split compounds. Such links show only that the forces of nature can turn into one another, not that they are the same thing, so chemical forces are not simply electricity.

2. Explain in your own words how chemical affinity differs from the cohesion that holds a crystal of salt together.

Hint: Think about which particles each force acts between, and whether something new is made.

Answer: Cohesion acts between particles of one and the same substance and gives a solid its shape, hardness and strength. Affinity acts between different substances and makes one enter into the other, so that a new substance is born. Both act only at the tiniest distances, which is why they have much in common.

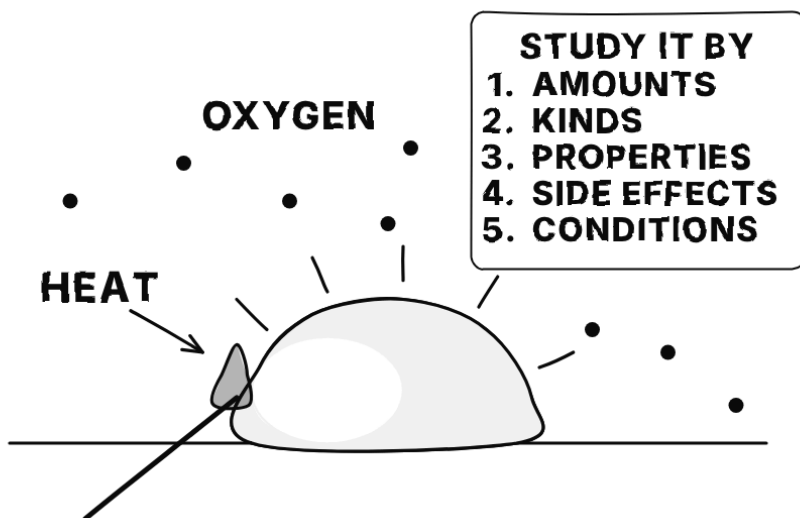
3. Several combinations in a row, each giving off heat, can leave a calm compound that hardly reacts. How can such a compound still take part in new reactions?

Hint: Think about what it could join with.

Answer: Its own store of chemical energy is small, but it can combine with an energetic simple substance or compound, and the new, more complex substance can again react readily.

A Window of Temperature

A lump of charcoal can lie in a bucket in open air for years and never burn. Touch one corner with a flame until it glows red, and the glow spreads, slowly at first, then across the whole lump. The oxygen was there all along, and so was the charcoal's urge to combine with it. What was missing was heat. This part is about how chemists study reactions, and about the conditions, temperature above all, that decide whether a reaction happens at all.

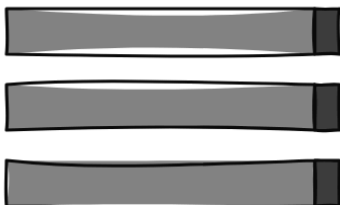


Charcoal Waits for Heat

Mendeleev names five ways of studying the course of a reaction. Measure how much of each substance takes part; sort reactions into kinds; see how properties change as composition changes; watch what goes with a reaction, such as heat, light and electricity; and find the conditions it needs. The first of these, stoichiometry, the study of weights and volumes in reactions, is by far the most advanced. Its laws, found by Dalton, Avogadro and others, reach into every corner of chemistry, and Mendeleev says his whole book is ruled by them. A lab scale in a factory that mixes exact weights of ingredients for every batch is stoichiometry put to daily work.

One of its first fruits was a new way of sorting compounds. Around eighteen hundred, the Frenchman Proust showed that many compounds always hold their parts in exactly the same proportion by weight, whatever you do. Red mercury oxide, for instance, always has two hundred parts of mercury to sixteen parts of oxygen. An alloy of copper and silver is different: you can add as much of either metal as you like and still get a uniform whole, just as you can stir more or less sugar into water. So there are definite compounds, with fixed proportions, and indefinite ones, such as alloys and solutions. Both matter equally in nature and industry, but the laws of proportion were worked out mainly for the definite ones, so the others are less well understood. Sweeten your tea with one spoon or three, and it is still sweet tea; but the composition of water itself is always the same.

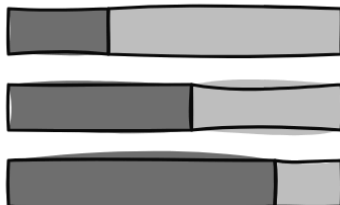
MERCURY OXIDE



Hg : O = 200 : 16

DEFINITE

COPPER + SILVER

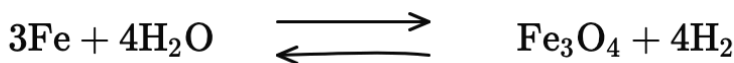


ANY PROPORTION

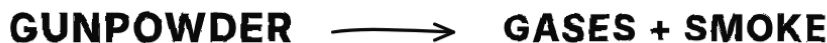
INDEFINITE

Fixed and Free Proportions

Mendeleev's next distinction is between reactions that can run backwards and those that cannot. Salt dissolves in water, and at the same temperature the solution can give back salt as the water evaporates. Iron, heated, takes oxygen from water vapour and sets hydrogen free; at that same temperature, hydrogen can take the oxygen back from the iron oxide and give iron and water again. In a reversible reaction like this, starting from either side, you end up with all four substances present together, in a chemical balance, or equilibrium. Add more of one substance and the balance shifts, which lets chemists study how the amounts of the substances steer a reaction. Gunpowder, on the other hand, burns into gases and smoke that will never, at any temperature, turn back into saltpetre, sulphur and charcoal.



BALANCE



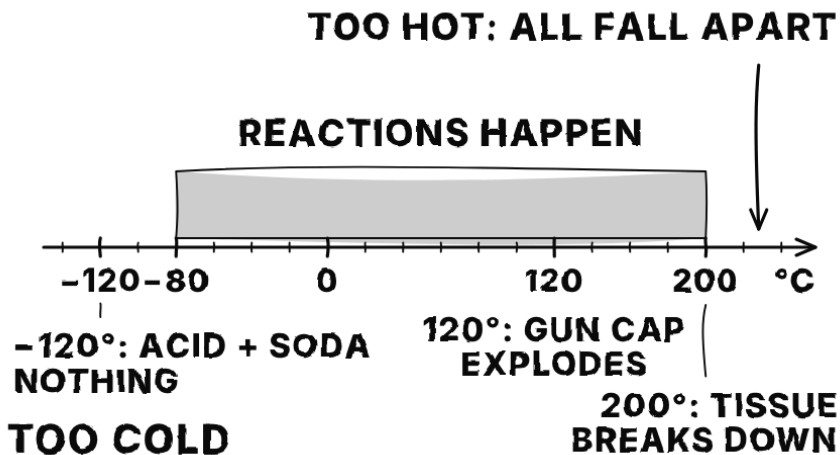
Reactions That Run Back

Some things will not combine directly at all, and chemists have a way round it. Chlorine reacts neither with charcoal, nor graphite, nor diamond, yet stable compounds of chlorine and carbon exist. They are made by letting chlorine act on compounds of carbon and hydrogen: chlorine pulls the hydrogen away, and the carbon, just set free, joins with more chlorine. Chemists said such substances combine at the moment of their release, when they meet in a fresh, newly freed state.

Every reaction also gives rise to heat, light, motion or electric current, and each of these can in turn steer a reaction. For Mendeleev this shows that all of nature's phenomena are forms of motion, visible or invisible. Heat itself has a mechanical measure: four hundred and twenty-five kilogram-metres of work are worth one large calorie of

heat. A dynamo turns motion into current, and the same machine fed with current turns. The same electric motor that drives a kitchen mixer would make current if you spun it by hand, which is the reversibility Mendeleev describes. He admits there is no proper theory of these links yet, and he sets them aside for physical chemistry.

Which brings us back to the charcoal. Besides the amounts and the nature of the substances, a reaction needs the right conditions, often far from the everyday ones, and temperature comes first. Burning charcoal releases heat that warms the next layer until it glows, and only so does the fire spread. Combinations happen only within a certain range of temperature. Chlorine, and even common salt, combine with water only below freezing; above it, those compounds break apart. Heat helps in two ways: melting or boiling a substance brings its particles into closer contact, and warmth loosens the cohesion that holds particles of one substance together.



Each Reaction Has Its Window

Push the heat high enough, and every compound falls apart. Some go at very low heat: the fulminate in a gun cap explodes a little above one hundred and twenty degrees, and much of the tissue of plants and animals breaks down near two hundred. At the other end, cold stops chemistry. Plants halt their chemical work in winter, and in eighteen ninety-two Raoul Pictet, cooling with liquefied gases, found that below minus one hundred and twenty degrees even sulphuric acid and caustic soda will not react, and acid does not redden litmus until it is warmer than minus eighty. So each reaction has its window of temperature, and on the scorching sun or the frozen moon, many of the reactions we know on earth cannot happen. A refrigerator works on exactly this window: cold slows the reactions that spoil food, and the oven opens the window wide for baking.

This part leaves out the finer details of the laws of proportion and the theory of chemical mechanics, which Mendeleev himself leaves for later.

Remember

Chemists study reactions by measuring the amounts involved, sorting reactions, linking properties to composition, watching what goes with them, and finding their conditions. Measuring amounts, stoichiometry, is the most advanced, and showed that many compounds have fixed proportions while alloys and solutions do not. Some reactions run both ways and settle into a balance; others, like burning gunpowder, never run back. Heat, light, motion and electricity both arise from reactions and can steer them. Every reaction happens only within a range of temperature: too cold and nothing reacts, too hot and every compound falls apart.

Questions

1. Charcoal lies in open air for years without burning. What does this show?
 - a. That charcoal has no affinity for the oxygen of the air
 - b. That the air around it holds too little oxygen to burn anything
 - c. That a reaction needs the right conditions, here enough heat, and not only the right substances

- d. That charcoal burns only when it is ground into a fine powder
2. Why is an alloy of copper and silver called an indefinite compound, while red mercury oxide is a definite one?
- Because the alloy can be made with any share of either metal, while the oxide always has the same proportion
 - Because the alloy is a mixture of metals and the oxide contains a gas
 - Because the alloy can be separated by heat and the oxide cannot
 - Because the alloy is made in factories and the oxide is found in nature
3. Iron and water vapour at a certain temperature give iron oxide and hydrogen, and at that same temperature hydrogen and iron oxide give iron and water. What do you find if you start from either side?
- Only iron oxide and hydrogen, since iron always wins the oxygen
 - Only iron and water, since the reverse reaction is stronger
 - Nothing changes, because the two reactions cancel out
 - All four substances together, in a chemical balance
4. Why can chlorine and carbon form compounds even though chlorine does not react with charcoal, graphite or diamond?
- Because chlorine reacts with carbon once it has been cooled below freezing
 - Because chlorine pulls hydrogen away from compounds of carbon and hydrogen, and the freshly freed carbon joins with

chlorine

- c. Because diamond turns into charcoal when chlorine touches it
- d. Because chlorine and carbon combine whenever an electric current passes

Answers

- 1. c) The oxygen and the charcoal's urge to combine were there all along; what was missing was heat to start the reaction.
- 2. a) The oxide always holds 200 parts of mercury to 16 of oxygen, while the alloy stays uniform with any amount of either metal.
- 3. d) In a reversible reaction both directions go on at once, so all four substances end up present together in equilibrium.
- 4. b) The carbon meets chlorine at the moment of its release, in a fresh state in which it combines more readily.

Worked examples

The fixed proportion in mercury oxide Red mercury oxide always holds 200 parts by weight of mercury to 16 parts of oxygen. How much mercury and how much oxygen are in 108 grams of the oxide?

The proportion is fixed, so every 200 plus 16, that is 216 parts of oxide, hold 200 parts of mercury and 16 of oxygen.

108 grams is exactly half of 216.

So it holds half of each: half of 200 is 100 grams of mercury, and half of 16 is 8 grams of oxygen.

Check by conservation of matter: 100 plus 8 is 108 grams, the weight of the oxide.

Answer: 100 grams of mercury and 8 grams of oxygen

Practice

1. How many grams of oxygen can be driven out of 54 grams of red mercury oxide, if it holds 200 parts of mercury to 16 of oxygen?

Hint: Find what part of 216 is 54.

Answer: 4 grams. 54 grams is a quarter of 216, so it holds a quarter of 16 parts of oxygen, which is 4 grams; the other 50 grams are mercury.

2. According to the book, 425 kilogram-metres of work are worth one large calorie of heat. How much work is worth three such calories?

Hint: The measure is fixed, so work and heat grow together.

Answer: 1275 kilogram-metres: three times 425. Since heat is a form of motion, a fixed amount of work always answers to a fixed amount of heat.

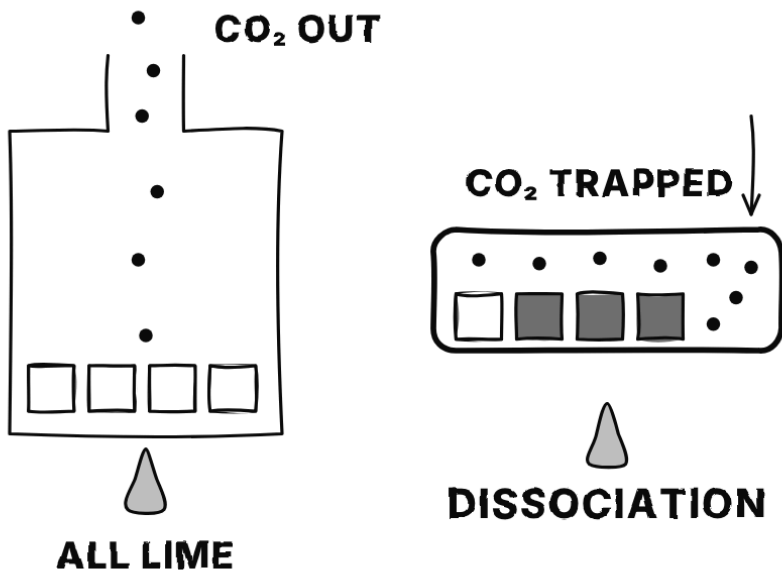
3. Raoul Pictet found that below minus 120 degrees even sulphuric acid and caustic soda do not react. Explain, using the idea of a window of temperature, why many reactions familiar on earth could not happen on the frozen moon or the scorching sun.

Hint: Think about what happens to reactions when it is too cold and to compounds when it is too hot.

Answer: Each reaction goes only within a certain range of temperature. Too cold, and even strong substances stop reacting, as Pictet showed; too hot, and every compound falls apart. On the moon and the sun the temperatures lie outside the windows of many of our reactions.

Halfway Apart

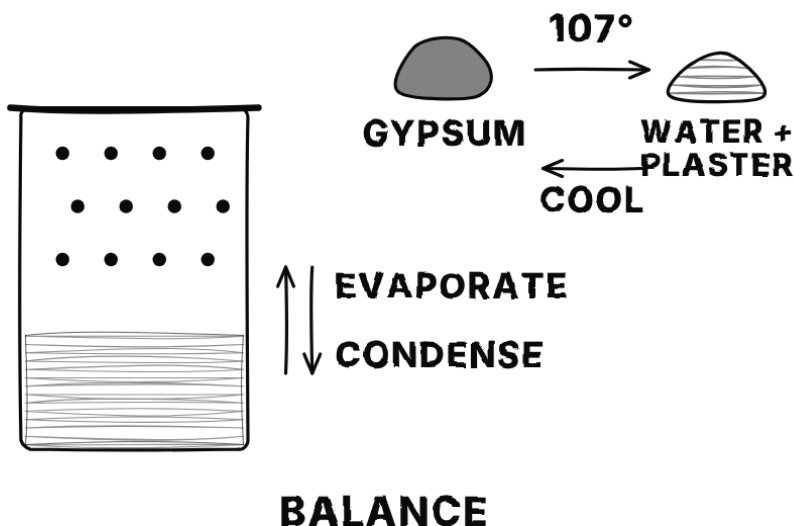
Put a piece of limestone into a lime kiln, fire it hot, and after some hours it has turned entirely into quicklime, its carbon dioxide gone up the chimney. Now do the same with the stone sealed inside a closed iron tube, the way Mendeleeev describes a riveted gun barrel. Heat it just as fiercely, and only part of the stone breaks down. The rest stays as it was, however long you wait. The difference is that in the kiln the gas can escape, and in the sealed tube it cannot.



Open Kiln, Sealed Tube

This half-finished breakdown is called dissociation, an idea brought into chemistry by Henri Sainte-Claire Deville. Heat a compound that can be rebuilt from its own products, in a closed space, and at a certain temperature it starts to come apart, but only a share of it. Raise the temperature, and the share grows; for every temperature there is its own balance between broken and unbroken substance, until at last everything comes apart. In the sealed tube, the carbon dioxide piles up until its pressure reaches the greatest value that temperature allows, and then the breakdown stops. Pump in more gas, and lime and gas combine again; let some gas out, and more stone breaks down.

Mendeleev compares this to water evaporating in a closed jar. The vapour gathers until its pressure is as high as that temperature allows, and then evaporation stops. Add vapour, and some condenses back to liquid; take vapour away, and more water evaporates. Breaking down and building up meet at a balance, just as evaporating and condensing do. A sealed bottle of fizzy water shows the same thing: the gas stays dissolved while the cap is on, and bubbles out as soon as you open it and let the pressure go.

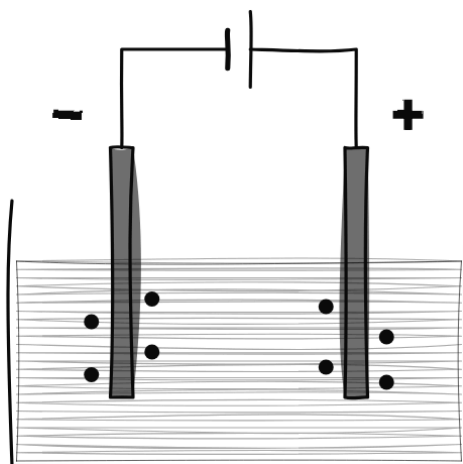


A Balance Like Evaporation

Some changes even have a sharp temperature, like a melting point. Natural gypsum, heated in a closed space, comes apart at one hundred and seven degrees into a wet mush: part of its water goes free as liquid, and a different salt, holding much less water, remains. Below that temperature, the gypsum forms again. Builders use this every day: the plaster of a wall or a cast is gypsum that was heated to drive off water, and when mixed with water again it sets back into gypsum.

Heat is not the only thing that sways reactions. An electric current does much the same: it splits most compounds that conduct it, and near those conditions it can also make substances combine. Its great advantage is that it works at room temperature and can split even the

most stubborn compounds. The parts appear at the two poles: metals and hydrogen at the negative pole, oxygen, chlorine and acids at the positive one. In this way the Englishman Humphry Davy did what Lavoisier could not, and won the metals potassium and sodium out of their compounds. With dynamos now giving cheap current, Mendeleev notes, factories make sodium and chlorine the same way. Aluminium foil in your kitchen drawer is made in just this way today, by passing a huge current through a molten aluminium compound.



Davy: K, Na O₂, Cl₂

Current Splits Compounds

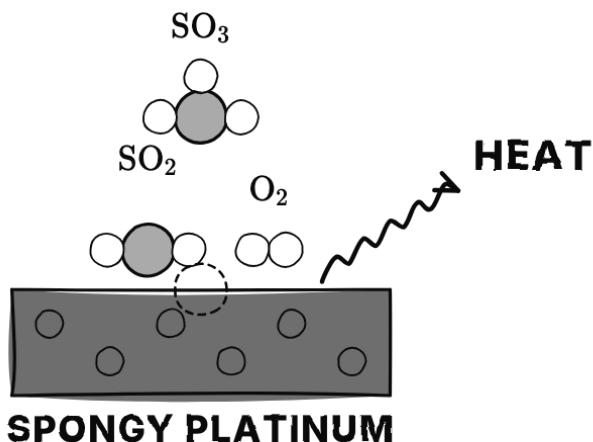
Light can do it too, though its push is weak, so only fragile compounds break, like the silver salts on which photography rests. Yet in green plants light achieves what heat and current struggle with: it splits carbon dioxide and sets oxygen free, a feat chemists of Mendeleev's

day could not copy. A blow or friction can be enough as well: the fulminate in a gun cap explodes when struck, and rubbing sulphur with a certain salt makes it burn. Pressure matters, especially for gases, because squeezing them brings their particles into closer contact.

Time matters, because particles must reach each other, and even then the inner change takes its own time. Young wine has acids and alcohol side by side; as it ages, they slowly react into water and fragrant esters, which give old wine its bouquet. Most of the sharp reactions a student meets first, though, run so fast that time can be ignored.

Finally, contact. The more points where substances touch, the faster they react: shake sulphuric acid with a gas for a long time and it absorbs it, and solids react best when ground to the finest powder. At the surface of a substance, its particles are pulled from one side only, so their state differs from that in the depth, as if they were warmer. That explains contact reactions, set off by the mere presence of certain bodies, especially porous ones like spongy platinum and charcoal. Sulphur dioxide and oxygen will not combine on their own, but beside spongy platinum they do, and release heat. The catalytic converter under a car works on this principle, with a fine coating of platinum metals helping the exhaust gases react.

MATTER IS CONSERVED ENERGY IS CONSERVED



Spongy Platinum Brings Them Together

Here Mendeleev closes the introduction. These general ideas, he says, only take on their full meaning when we meet the substances themselves, one by one. But two laws had to come first, the conservation of matter and the conservation of energy, because only with them in hand can the details be sorted sensibly and fruitfully.

This part leaves out the exact pressures of dissociation and the many further examples, which Mendeleev promises to develop later in the book.

Remember

Dissociation is a partial breakdown: in a closed space each temperature has its own balance between broken and unbroken substance. If a product can escape, as carbon dioxide leaves a lime kiln, the breakdown goes all the way to the end. Electric current, light, blows, pressure, time and close contact all steer reactions, just as heat does. Some bodies, like spongy platinum, make reactions happen by their mere presence. Beneath all the details stand two laws: matter is conserved, and energy is conserved.

Questions

1. Why does limestone break down completely in a kiln but only partly in a sealed iron tube at the same heat?
 - a. Because the iron of the tube cools the stone and slows the reaction
 - b. Because in the kiln the carbon dioxide escapes, while in the tube it builds up and stops the breakdown
 - c. Because the kiln is open to the air, and oxygen is needed to break limestone
 - d. Because limestone in a tube melts instead of breaking down
2. In the sealed tube the breakdown has stopped. What happens if more carbon dioxide is pumped in at the same temperature?

- a. Lime and carbon dioxide combine again, rebuilding some limestone
 - b. More limestone breaks down, because there is more gas to carry it off
 - c. Nothing, because the reaction has already reached its end
 - d. The lime melts into a wet mush, as gypsum does
3. What makes the electric current especially useful for splitting compounds?
- a. It splits only weak compounds, leaving the strong ones untouched
 - b. It makes every part of a compound appear at the same pole
 - c. It works at room temperature and can split even the most stubborn compounds
 - d. It needs no conducting liquid or melt to pass through
4. Why do substances react more readily on the surface of spongy platinum?
- a. Because platinum gives up part of itself to each new compound
 - b. Because the platinum heats the gases by burning in them
 - c. Because platinum removes the products, as the kiln removes carbon dioxide
 - d. Because at a surface particles are pulled from one side only, and their state is changed as if warmed

Answers

1. **b)** In the closed tube the gas piles up until its pressure is the greatest that temperature allows, and then the breakdown stops; in the kiln it simply

leaves.

2. a) Like vapour added to a closed jar, extra gas pushes the balance back, and some of the products recombine.

3. c) Unlike heat, the current breaks compounds at ordinary temperature, which is how Davy won potassium and sodium.

4. d) On the surface of a porous body the state of the touching substances is altered as by a rise in temperature, so they react on contact.

Worked examples

How much water gypsum gives up At 107 degrees, in a closed space, gypsum comes apart into a mush: three quarters of its water is set free as liquid, and a salt holding the rest remains. A piece of gypsum holds 20 grams of water. How much water is freed, and how much stays in the salt?

The book says three quarters of the water goes free as liquid at this temperature.

Three quarters of 20 grams is 15 grams.

The rest, one quarter, stays bound in the new salt: 20 minus 15 is 5 grams.

Below 107 degrees the water and the salt rebuild gypsum, so the change runs both ways.

Answer: 15 grams freed as liquid, 5 grams kept in the salt

Practice

1. Using Mendeleev's comparison with water evaporating in a closed jar, explain why limestone sealed in a tube stops breaking down at a given temperature, and what letting gas out would do.

Hint: What stops evaporation in a closed jar, and what restarts it?

Answer: In the jar, vapour gathers until its pressure is the greatest the temperature allows, and evaporation stops; taking vapour away lets more water evaporate. In the same way the carbon dioxide in the tube reaches its dissociation pressure and the breakdown stops; letting gas out lowers the pressure, and more limestone breaks down.

2. Young wine and old wine contain the same acids and alcohol at first. Why does old wine have a bouquet that young wine lacks, and what does this show about reactions?

Hint: Think about how fast this particular reaction runs at ordinary temperature.

Answer: The acids and the alcohol slowly react into water and fragrant esters, but at ordinary temperature this takes a long time. It shows that, besides contact, a reaction needs its own time, and some reactions run slowly enough for time to matter.