THE MYSTERY OF MATTER: SEARCH FOR THE ELEMENTS

EPISODE 1 (OF 3): OUT OF THIN AIR
BROADCAST NATIONALLY ON PBS AUG. 19, 2015

The film opens with a two-minute prologue. Reenactment: In a dank alchemist's laboratory, a white-bearded man works amidst a clutter of vessels, bellows and furnaces.

NARR: One night in 1669, a German alchemist named Hennig Brandt was searching, as he did every night, for a way to make gold.

Brandt lifts a flask of yellow liquid and inspects it.

NARR: For some time, Brandt had focused his research on urine. He was certain the "golden stream" held the key.

Brandt places the flask on the forge and moves to another vessel where urine has been heating for some time.

NARR: Tonight his patience would at last be rewarded. He had boiled the urine down to a concentrated paste. Now he subjected it to intense heat.

The vessel begins to glow with an eerie, pale-green light. CU of Brandt's face, his excitement evident.

NARR: Was this the legendary elixir that would turn lead into gold?

Alchemy painting of Brandt in the laboratory, his face lit green by glowing phosphorus. Dissolve to a second alchemy painting.

NARR: Alas, it was not. Brandt had stumbled on the element phosphorus. This is how the discovery of elements began – with people trying to turn the substances of nature into something useful or valuable.

The host stands behind a table strewn with an assortment of things suggesting the long human tradition of working with materials – rocks, metals, tools, etc. He picks up a rock from the table.

HOST

But people are naturally curious, so as they worked with these materials they began to wonder: What is this stuff? *What is the world made of?*

On a panel behind the host we see an animation of the ancient Greek philosopher Empedocles and his four elements. The image becomes full screen.

HOST

Thousands of years ago, the Greeks proposed that the world is actually made of just four elements in combination: air, water, earth and fire.

The Periodic Table replaces the four elements on the panel behind the host.

HOST

Today we know that matter actually comes in more than 100 distinct varieties, neatly arranged in the Periodic Table of the Elements. But for most of history, matter was a profound mystery – a 2,000-year detective story in which people across the world were trying to identify the elements … and figure out how to use them.

Composite image of the series' seven main characters

NARR: It's an amazing story, filled with unforgettable characters. In this series, you'll meet seven extraordinary scientists whose findings drove the search for the elements. So join me as we retrace the steps of these "chemical detectives" as they struggle to solve the mystery of matter.

Title Sequence and Opening Credits

Episode title: Out of Thin Air

Fade up to host in studio. To his left is a panel showing moving images of grass waving in the wind.

HOST

One of the first big clues in solving the mystery of matter came from the discovery of most *immaterial* stuff you can imagine: air.

Images of clouds now appear on the panel.

HOST

Of course, people have always known about air. They could feel the wind on their faces and see its powerful effects in storms. What they didn't know was that there's more than one kind of "air."

Host motions to image of Joseph Black on the panel over his other shoulder.

HOST

That changed in 1754, when a young Scottish medical student named Joseph Black set out to find a cure for kidney stones.

Host pours acid on a chalky substance, releasing some kind of "air." CU of the bubbles formed. The gas bubbles up through a tube into a pitcher.

HOST VO

He poured acid on this chalky substance and trapped the air that came out. To his surprise, this "air" didn't behave like air at all.

He pours the pitcher over a lighted candle, which goes out.

HOST

It was heavier than ordinary air – and promptly put out a flame. Black's discovery of "fixed air" – what we now call carbon dioxide – was a turning point in the history of science. People had long known about liquids and solids. Now, suddenly, they realized there was a third state of matter – gases – of which air is just one example. Over the next 20 years, the exploration of this new dimension would transform our understanding matter.

Computer graphic combines images of Henry Cavendish and Daniel Rutherford, the names of the elemental gases they discovered and their dates of discovery: hydrogen (1766) and nitrogen (1772).

NARR: After Black's discovery, British scientists quickly identified two more new gases: hydrogen and nitrogen.

HISTORIAN SEYMOUR MAUSKOPF

And then in the early 1770s that astonishing investigator Joseph Priestley discovers all sorts of new "airs."

Archival image of Priestley dissolves to footage of him in the lab with his electrical apparatus.

NARR: Priestley was a minister by trade, but also an amateur scientist – what was then called a natural philosopher.

BIOGRAPHER STEVEN JOHNSON

He was a great dabbler in things and was constantly getting obsessed with new fields.

Priestley places a glass vessel over a plant.

NARR: Fields like the new science of gases.

Priestley continues experimenting with plants and candles under glass vessels. Then he pours acid on a substance to release the "air" it contains. The gas bubbles up in an overturned bottle.

HISTORIAN SEYMOUR MAUSKOPF, partly in VO

Priestley's style of science is very interesting. He's a kind of inspired forager. He's basically messing around with different things to see what will happen. One of the things Priestley did [laugh] was to pour acid on everything. He collected those bubbles, tested them thoroughly and discovered all sorts of amazing properties.

Superimposed on a wide shot of Priestley in the lab the scene is a graphic showing the nine new gases Priestley discovered.

NARR: By "messing around" in this way, Priestley discovered nine new gases – more than anyone else in the world.

BIOGRAPHER STEVEN JOHNSON, partly in VO

He was very much open to chance discoveries. He would stumble across things and he would follow his instincts. And he was always looking for these kind of fortuitous accidents.

Archival image of Leeds

NARR: One such accident happened in 1767, when Priestley was assigned a new congregation.

BIOGRAPHER STEVEN JOHNSON, partly in VO

They put him in a house that happens to be right next to a brewery. And this turns out to be an incredible [laugh] stroke of good luck. Priestley, being the kind of constant investigator that he was, would kind of pop over and see what was going on at this brewery.

Archival images of 18th century British breweries

NARR: Just above the vats of beer, he discovered a haze of carbon dioxide bubbling up from the fermenting brew.

BIOGRAPHER STEVEN JOHNSON

And he decided he wanted to do some experiments [laugh], with their beer. Well fortunately, they said yes.

Host pours water from one glass to another over the bubbling barrel.

HOST ON CAMERA

Priestley found that if he simply poured water from one glass to another over the surface, the water would absorb the gas rising from the beer. The result was refreshingly bubbly.

Lab reenactment of Priestley making soda water. Priestley stops adding acid and vigorously agitates the overturned vessel until the gas is absorbed.

NARR: By 1772, he had invented a better method: generating carbon dioxide and injecting it directly into water.

Words on screen: Words spoken by the characters in this film are drawn from their writings.

JOSEPH PRIESTLEY TO CAMERA

In the space of two or three minutes, I can make a glass of exceedingly pleasant sparkling water. [drinks] You can't tell the difference between this and natural mineral water.

Host behind beer barrel

HOST

Priestley had invented carbonation – remember that next time you enjoy a soft drink. But with this act he also set in motion a series of improbable events that would soon overturn our understanding of matter.

Priestley agitates his soda water vessel, then takes a sip.

NARR: It began when a British doctor suggested Priestley's "windy water" might be effective as a treatment for scurvy, a disease that plagued sailors on long sea voyages.

Archival image of sailor with scurvy

BIOGRAPHER STEVEN JOHNSON, partly in VO

Scurvy was a huge problem for the military during that period. And so the idea that there was this potential solution that also happened to be a tasty beverage [laugh] was appealing.

Title page of Priestley's paper: Directions for Impregnating Water with Fixed Air.

NARR: In 1772, Priestley addressed Britain's leading scientific organization, the Royal Society, and published a pamphlet describing his method for making soda water. He urged the British navy to test the potential cure.

Reenactment: Magellan picks up the pamphlet and reads it, then begins writing.

NARR: Quick to pick up on this development was a defrocked Portuguese monk named Joao Jacinto de Magellan. A distant relative of the great Portuguese navigator, he was now serving as a French industrial spy.

Magellan seals a package including Priestley's pamphlet.

BIOGRAPHER STEVEN JOHNSON, partly in VO

Magellan is in the employ of the French government and is there basically scouting out the Royal Society for interesting items that he might be able to bring back to his bosses.

NARR: Sensing a potential military secret …

Cut to Trudaine, reading Magellan's letter, then beginning to write his own. Priestley's pamphlet is alongside.

NARR: … Magellan alerted his handler back in France: Commerce Minister Jean Charles Trudaine de Montigny.

HISTORIAN SEYMOUR MAUSKOPF, partly in VO
Trudaine was interested in science, was a member of the French Royal Academy of Sciences, and immediately saw the possible value of this.

Lavoisier is working in his laboratory when his lab assistant comes in saying (in French) a letter has arrived from Trudaine. He hands the letter to Lavoisier, who opens the package and begins reading.

NARR: Trudaine, in turn, called on one of France's brightest young chemists, Antoine Laurent Lavoisier.

We hear the first of Trudaine's words in VO, then cut to him on camera writing the letter we're hearing. Occasionally we cut back to Lavoisier reading. He absorbs the meaning of this request. Trudaine delivers the last line to camera, with emphasis.

JEAN CHARLES TRUDAINE DE MONTIGNY, partly in VO
I know your precision when it comes to physics and chemistry, and I'm giving you a chance to be of service to your country. Please repeat these experiments and add your own observations. The value of these discoveries depends on our moving quickly. I hope you will not be long in getting this little work done.

Lavoisier now opens Priestley's pamphlet and begins to read.

HISTORIAN ALAN ROCKE, partly in VO
Trudaine probably intended this politely phrased letter as an order rather than a request. Lavoisier really couldn't ignore it.

NARR: Though soda water would turn out to be useless against scurvy, this pointed suggestion by a government official, acting on a tip from a Portuguese spy, would set Lavoisier on the path toward his greatest discoveries.

Dissolve to archival image of young Lavoisier

NARR: Born into a well-to-do Parisian family, Lavoisier had received a fine education and taken a degree in law. Now 28, he had joined a consortium that collected taxes for King Louis the XV.

Painting of the 18th century French court

HISTORIAN SEYMOUR MAUSKOPF VO
As a result, Lavoisier became a very wealthy man.

Laboratory reenactment: Antoine works in the lab. Cut to Marie Anne elsewhere in the lab.

NARR: But his true passion was chemistry. Lavoisier spent three hours in his private laboratory before work each day, and returned there after dinner … often accompanied by his young wife.

Marie Anne sketches a piece of lab equipment. Her water colors are laid out on the table before her. She calls Antoine, and he comes over to comment on her sketch.

MARIE ANNE LAVOISIER
Antoine?

ANTOINE LAVOISIER
Oui?

NARR: Marie Anne Paulze was the daughter of one of Lavoisier's business partners. She was just 13 when they were married … but bright, outgoing and mature beyond her years.

MARIE ANNE LAVOISIER
Lequel est-ce que tu préfères?

Continuing scene, then painting of Antoine and Marie Anne Lavoisier.

HISTORIAN SEYMOUR MAUSKOPF, partly in VO
Marie Anne was virtually his collaborator. She knew English, learned chemistry, assisted Lavoisier in the laboratory. She was an extraordinary person. Had she lived in our own time, she probably would have become an outstanding scientist in her own right.

Marie draws an illustration of one of Lavoisier's experiments on respiration, and we see it come to life in a reenactment.

NARR: One of Marie Anne's most important roles was to create the diagrams and illustrations that accompanied her husband's published work.

HISTORIAN ALAN ROCKE, partly in VO
Marie Lavoisier's drawings give us the eyes to look directly into Lavoisier's laboratory. We can see the people. We can see the devices. We can see the arrangement of those devices. We can understand what Lavoisier did so much better because of what Marie drew.

Lavoisier reads a book describing the work of another scientist.

NARR: Spurred on by Trudaine, Lavoisier eagerly studied fresh translations of Black, Priestley and the other British chemists who had pioneered the study of "airs."

He writes in his lab notebook.

ANTOINE LAVOISIER, partly in VO

The work of these previous experimenters merely hints at what's happening when air is taken up or released by different substances. I shall review all their work, repeat all their experiments, taking new precautions, in order to develop a coherent theory. This subject, I believe, is destined to bring about a revolution in physics and chemistry.

A fire burns in a fireplace. The word PHLOGISTON appears on the screen over this image.

NARR: What made this new science of air so revolutionary was that it threatened to topple the reigning theory of chemistry – a theory inspired by the mystery of fire. Most chemists believed fire was due to some fiery principle that was given up during combustion. And all our senses seem to confirm this idea. Heat, light, smoke – all are *released* as the fire burns. By the mid-1700s, this essence of fire had been given a name: phlogiston.

Image of a rotating bolt, showing both its rusty and shiny sides

NARR: Phlogiston was the foundation of chemistry's leading theory for nearly a century, because it seemed to explain things like metals and rust:

Animation labeled Phlogiston Theory shows that as iron ore is heated alongside charcoal, phlogiston from the charcoal merges with the ore to make metallic iron in the form of an ingot. Then, as a sprinkle of rain falls on the ingot, phlogiston begins leaving the ingot and it turns to rust.

NARR: When iron ore was heated in the presence of charcoal, phlogiston from the charcoal fused with the ore to form metallic iron. When the iron was exposed to air or water, the metal released its phlogiston as it rusted.

In the animation, a copper statue appears alongside the iron, ultimately turning into green verdigris.

NARR: Other metals went through the same process – forming the green verdigris of copper, for example.

Finally, the simple equation appears on the screen, along with the word "calx."

NARR: Ore plus phlogiston equals metal. Metal minus phlogiston equals rust – or what was then called a "calx."

In the animation, a scale is now in place under the iron bar. Paradoxically, it shows that the bar gets heavier as it gives off phlogiston and forms rust, also labeled "calx" in the animation.

HISTORIAN ALAN ROCKE, partly in VO
Only there was a problem: The calx was heavier than the metal, even though phlogiston had left the metal. It's lost something, and yet it was heavier.

ANTOINE LAVOISIER
The calx should weigh *less* than the original metal. But it doesn't. The calx is heavier than the metal.

Lavoisier works at his scale.

HISTORIAN ALAN ROCKE, partly in VO
Though many chemists were aware of this contradiction, they let it pass, because phlogiston otherwise worked so well. But Lavoisier was really troubled by this, because he was obsessed with the weights of his experimental ingredients.

CHEMIST GREGORY PETSKO, partly in VO
Lavoisier was very careful to get very good instruments. He probably, at one point, had the largest and most complete private laboratory on earth.

ANTOINE LAVOISIER, partly in VO
With my precision scales, imported from England at great expense, I measure the weight of each substance at the beginning and end of every chemical reaction.

Lavoisier at the scale

HISTORIAN ALAN ROCKE VO
Lavoisier was a master of this balance sheet kind of chemistry. Remember, he was tax administrator by day. He knew a lot about accounting. And so this kind of ledger-keeping was natural to him.

ANTOINE LAVOISIER
It is a fundamental truth of chemistry that the same amount of matter exists before and after each experiment. Nothing new is created, nothing lost. The whole art of performing chemical experiments rests on this principle.

CU of scale and Lavoisier

NARR: Today, we call this idea the Conservation of Matter.

HISTORIAN SEYMOUR MAUSKOPF
When you carry out a chemical reaction, what comes out has to be exactly equal to what goes in.

ANTOINE LAVOISIER
The total weight must remain precisely the same. If not, there's an error somewhere.

Footage of Lavoisier weighing

HISTORIAN ALAN ROCKE, partly in VO

He wasn't the first to assume Conservation of Matter, but Lavoisier applied this idea more rigorously than anyone had before. And it worked very effectively as a tool – a tool of discovery.

In the lab, Lavoisier uses a spatula to mix a lead calx known as minium with powdered charcoal in a crucible.

NARR: The power of Lavoisier's method would become clear in October 1772, when he set out to solve the riddle of why metals gain weight when they form calxes.

CHEMIST GREGORY PETSKO

Common sense suggested that when things rust they must lose weight. They fall apart. They become brittle and weak. Lavoisier was interested in actually measuring what happened.

Closeups and moves on an engraving of the gigantic double lens that the Academy of Sciences rolled out for a series of experiments in the summer and fall of 1772. CU of the men and women watching in the background.

NARR: He conducted his experiments in public, relying on a huge burning lens that focused the sun's rays to produce intense heat … while elegantly dressed bystanders watched in amazement.

Zoom to crucible showing a mixture of lead and charcoal. The next shot shows Lavoisier marking the water level at the beginning of the experiment, with a small piece of paper glued to the outside of the bell jar.

NARR: Lavoisier placed a calx of lead, mixed with charcoal, inside a glass vessel partially filled with water …

The apparatus is suddenly washed in sunlight, and a narrow beam of light is focused on the crucible under the bell jar. Lavoisier leans down and puts on his sunglasses. The water level drops rapidly below the piece of paper.

NARR: … then subjected it to the intense heat of the burning lens. The result was extraordinary.

ANTOINE LAVOISIER, partly in VO

As the calx changes back into the metal, it releases a large quantity of air. This air forms a volume *a thousand times greater* than the calx it came from.

Footage of Lavoisier watching his experiment, then animation of his proposed explanation

NARR: This startling finding suggested a radical idea: If air came ***out*** as the calx changed back into a metal, could it have gone ***in*** when the calx was formed? Could *air* be reason calxes were heavier than expected?

Back in the lab, Lavoisier uses the spatula to place yellow sulfur powder in the crucible.

NARR: Lavoisier also found that when he *burned* elements like sulfur, they, too, gained weight.

ANTOINE LAVOISIER
There was then no doubt. I realized that the increase in weight occurs because a portion of the air is absorbed into the solid material.

Lavoisier makes a final notation in his report on his experiments. Then he seals his note with wax.

CHEMIST ROALD HOFFMANN, partly in VO
He knew he was onto something very important. He knew that the element did not lose mass. It gained mass. It *took up* some part of the air.

ANTOINE LAVOISIER, partly in VO
I felt I must secure my right to this important discovery. So I deposited a note with le Secretaire de l'Academie, to remain sealed until I was ready to make my experiments public.

HISTORIAN SEYMOUR MAUSKOPF
He's discovered what seems to be evidence by weighing things, that seemed to flatly contradict what the phlogiston theory is predicting.

Reprise of rust and fire images

NARR: Despite what our senses tell us, both rusting and burning involve *absorbing* something from the air – just the opposite of what chemistry's reigning theory held.

Continuing shots of Lavoisier at the scale

HISTORIAN ALAN ROCKE, partly in VO
It had been known for a hundred years that metals gain weight when they become calxes. But no one had bothered to really investigate this anomaly. By focusing so intently on weight, Lavoisier had challenged the very foundation of chemistry. And he'd identified the source of that weight gain. Air was somehow involved.

Frustrated by an experiment gone wrong, Lavoisier slams a leaky retort to the ground. It shatters with a loud pop.

NARR: But was it air itself, or some part of the air, and, if so, what part? The identity of the mystery gas eluded him for two years.

Marie Anne and Antoine discuss his findings at the dining room table over morning coffee. We hear snippets of their conversation in French.

MARIE ANNE LAVOISIER

Un gaz? Mais lequel?

ANTOINE LAVOISIER

Je ne sais pas …

NARR: He was still stumped in late 1774. But the answer would soon be delivered …

Footage of Priestley in the lab with the red calx of mercury

NARR: … by Joseph Priestley. By this time, Priestley had begun to study something called the red calx of mercury.

CU of liquid mercury on a tabletop

NARR: Mercury is a strange metal – one of just two elements that is liquid at room temperature.

Pan to reveal its red calx alongside

NARR: But like other metals it forms a calx – a red solid that pharmacists of the 1700s used to treat venereal disease. Chemists had noticed something unusual about this calx.

Widen out to reveal both mercury and its calx

NARR: They could convert it back into metallic mercury simply by heating it. No charcoal – no source of phlogiston – was needed.

Priestley gazes out a window.

NARR: This was theoretically impossible. How could it be?

Priestley continues his experiment with mercury calx. He places a sample of (fake) mercuric oxide in a glass retort, then uses his burning lens to focus a spot of sunlight on the sample. The red powder begins to turn black. Gas bubbles up in his pneumatic trough, displacing the water in an overturned receiving vessel.

NARR: The ever-curious Priestley wanted to know. So in August 1774, he obtained a sample of mercury calx and used his own burning lens to heat it with sunlight.

CHEMIST ROALD HOFFMANN, partly in VO

That reddish substance in turn decomposes, giving back mercury, but also a gas.

When the gas has driven all the water out of the vessel, he slides a plate under the vessel and moves it to another part of his workbench. He lifts it slightly to insert a lighted candle, expecting it to go out. Instead, to his surprise, the candle burns bigger and brighter than the candle alongside in a vessel of ordinary air.

HISTORIAN SEYMOUR MAUSKOPF VO
Priestley collects this air, because he likes to test these gases to see what properties they have.

NARR: If it were his old friend "fixed air," the candle would go out.

HISTORIAN SEYMOUR MAUSKOPF VO
But what he found about this air was that it had quite extraordinary properties.

Priestley leans down to examine the two candles. One is out, while the one in the new air continues to burn brightly.

JOSEPH PRIESTLEY, partly in VO
What astounded me was that the candle burned in this air with remarkable vigor. The flame was bigger – and brighter – than in ordinary air.

BIOGRAPHER STEVEN JOHNSON VO
Something in this air seems almost better than normal air, which is very puzzling.

Priestley inserts a piece of "red hot wood" into the vessel. It bursts into flame. He stoops down to look at it, astonished.

JOSEPH PRIESTLEY, partly in VO
I was utterly at a loss. How could I explain this?

Cut to reenactment of Paris dinner with Antoine and Marie Lavoisier and other French scientists. While others are chattering away in French, Madame Lavoisier makes a special point of speaking to Priestley in English, in which she (unlike Antoine) is fluent.

JEAN CHARLES TRUDAINE DE MONTIGNY
*Buvons à la santé d'Archimède**!***

MARIE ANNE LAVOISIER
Dr. Priestley, have you been to the Continent before?

JOSEPH PRIESTLEY
No, this is my first time.

NARR: Two months later, on a visit to Paris, Priestley was invited to dine with members of the Royal Academy of Sciences … including Antoine Lavoisier.

JOSEPH PRIESTLEY

J'ai récemment réalisé …

HISTORIAN SEYMOUR MAUSKOPF

Priestley tells Lavoisier in his very broken French about his new discovery.

JOSEPH PRIESTLEY

… avec les résultats tres intéressants.

JOSEPH PRIESTLEY, partly in VO

I described this experiment at the table of Monsieur Lavoisier. I never make the least secret of anything that I do.

JOSEPH PRIESTLEY

… la même aire de plombe rouge.

BIOGRAPHER STEVEN JOHNSON, partly in VO

Everything that he came up with, every new experiment that he did, even when he wasn't sure what the results meant …

JOSEPH MACQUER

Que est-ce que se ce plombe rouge?

BIOGRAPHER STEVEN JOHNSON, partly in VO

… he was constantly sharing that information with as many people as possible.

JOSEPH PRIESTLEY

Mais à ma grande surprise …

PRIESTLEY VO continues

I also told them that it produced a kind of air in which a candle burned much better than in common air.

JOSEPH PRIESTLEY

… mieux que dans l'air commun.

The men and women around the table, including Antoine and Marie Anne Lavoisier, exchange surprised glances. "Mieux?"

JOSEPH PRIESTLEY, partly in VO

At this the entire company – including Monsieur and Madame Lavoisier – expressed great surprise. I'm sure they cannot have forgotten these events.

Intrigued, Antoine questions Priestley intently, with Marie Anne translating.

ANTOINE LAVOISIER

Monsieur Priestley, etes-vous bien sûr que ce n'était pas l'air fixe?

MARIE ANNE LAVOISIER

If you want, I can translate for you.

JOSEPH PRIESTLEY

Aha. Merci.

MARIE ANNE LAVOISIER

Are you sure that what you found was not fixed air?

JOSEPH PRIESTLEY

Absolutely. But I'm not yet sure what it was.

Dinner scene continues.

HISTORIAN SEYMOUR MAUSKOPF, partly in VO

Lavoisier did not appreciate Priestley's style. He didn't think Priestley brought very much thought to his scientific foraging.

Lavoisier listening intently

BIOGRAPHER STEVEN JOHNSON, partly in VO

But Lavoisier was smart enough to recognize that Priestley was onto something and take that piece of information and go back to his lab to figure out exactly what Priestley had discovered.

Lavoisier and his assistant leave the lab.

NARR: Could this be the gas he was looking for – the one involved in rusting and burning? Lavoisier hurried to the local apothecary to buy his own sample of mercury calx.

Priestley uses his electrostatic generator to amuse his eight-year-old son.

JOSEPH PRIESTLEY (to son)

"Look what you can do."

NARR: Back in England, Priestley dithered for months on other projects, unaware he was in danger of being scooped.

A thought occurs to Priestley as he wipes out a glass vessel.

NARR: Finally, it occurred to him: If this gas he had discovered supports fire, might it also support breathing?

He pulls a mouse out of its cage and places it under a bell jar. Priestley jots down a note while watching the mouse closely.

BIOGRAPHER STEVEN JOHNSON, partly in VO
Here we have one of the great discoveries in the history of chemistry, and the scene is kind of amazing. You've got this man and a mouse [laugh].

JOSEPH PRIESTLEY, mostly in VO
I put a mouse into a glass vessel containing two ounces of the air from the heated calx of mercury. If it were common air, a full-grown mouse would have survived in it perhaps a quarter of an hour.

Close-ups of the mouse – perfectly comfortable as time passes

BIOGRAPHER STEVEN JOHNSON VO
15 minutes pass … 20 minutes pass.

Priestley consults his pocket watch to see how much time has passed.

JOSEPH PRIESTLEY, partly in VO
In this air, my mouse remained perfectly at ease for a full half hour.

Close-up of the frisky mouse

BIOGRAPHER STEVEN JOHNSON VO
That's twice as long as any mouse has ever survived.

He removes the mouse, which seems none the worse for wear.

JOSEPH PRIESTLEY, partly in VO
I began to suspect that the air into which I had put the mouse was *better* than common air.

Now Priestley puts the mouse back under glass in the same air it has just breathed for half an hour.

BIOGRAPHER STEVEN JOHNSON, partly in VO
He takes the same mouse and sticks it back under the glass and, sure enough, the mouse survives another 30 minutes in this strange new air.

Priestley stoops down and smiles as the mouse grooms itself.

BIOGRAPHER STEVEN JOHNSON VO
He realizes that something fundamentally different has happened. This air is some kind of super air.

Priestley watches the mouse.

JOSEPH PRIESTLEY, partly in VO
I concluded that this air was between five and six times better – that is, more breathable – than the best common air I had ever tested.

He removes the mouse from under the jar.

BIOGRAPHER STEVEN JOHNSON, partly in VO
He finally has kind of convinced himself this air must be safe to breathe if the mouse is doing so well. And so he gets up enough courage to actually try it himself.

Priestley holds a tube up to his mouth, breathes in some of the gas, stops to consider the sensation, and then talks to camera.

JOSEPH PRIESTLEY
It doesn't feel any different from ordinary air when I breathe it in. But I feel peculiarly light and easy. In time, this pure air may be useful as a medicine or sold to the fashionable for recreation. Up to now, only two mice and I have had the privilege of breathing it.

Antoine and Marie in the Paris lab perform their own experiments on this new air. He removes the vessel from the trough and takes it to testing area. He inserts a lit candle, which leaps up and burns brightly.

BIOGRAPHER STEVEN JOHNSON VO
As Priestley is conducting these experiments in England, across the channel, Lavoisier is basically going through the exact same experiments.

CHEMIST ROALD HOFFMANN, partly in VO
Lavoisier, realizing that this is essentially the key to the mystery, gets to work on it.

Charcoal throws out sparks. Antoine and Marie Anne laugh at the sight.

ANTOINE LAVOISIER, partly in VO
I found – much to my surprise – that this air had none of the properties of "fixed air." A candle burned in it with a dazzling splendor; and charcoal, instead of just smoldering, threw out sparks in all directions.

Painting of the Academy building

NARR: Lavoisier announced his findings with great fanfare at the 1775 Easter meeting of the Academy of Sciences:

ANTOINE LAVOISIER, partly in VO

All this evidence convinced me that this air is more … [searching for words] breathable – more combustible – and more pure than even the common air in which we live.

BIOGRAPHER STEVEN JOHNSON

And he gives it the name oxygen.

Reprise dinner scene

NARR: In announcing his findings, Lavoisier made no mention of Priestley's revelation over dinner six months earlier.

CHEMIST ROALD HOFFMANN, partly in VO

Now, Priestley is not a shrinking violet here. He hears about this, and he objects.

JOSEPH PRIESTLEY

He should have acknowledged the fact that my account over dinner led him to try the experiment. One should not put one's scythe into another man's harvest.

ANTOINE LAVOISIER

I admit I was not the first to do these experiments. That claim goes to Mr. Priestley. But from the results we have drawn diametrically opposite conclusions. I may be criticized for having borrowed from the work of this celebrated philosopher, but I trust that the originality of my conclusions will not be challenged.

Lavoisier in lab reenactment scenes

NARR: Lavoisier was right. While it was Priestley who made the discovery, it was Lavoisier who grasped the implications of this new gas.

CHEMIST ROALD HOFFMANN, partly in VO

Lavoisier was the only one who understood what was going on. Perhaps he didn't understand perfectly, but the moment that new element, which we call oxygen, was there, he picks it up and he runs with it.

Lavoisier writes. Then an image of the atmosphere, with the names of its constituents – nitrogen and oxygen – superimposed.

NARR: Over the next 15 years, Lavoisier would show that air is not a simple substance, as the ancients believed, but a mixture of two newly discovered gases …

Image of water with its constituents overlaid: hydrogen and oxygen

NARR: … that water, too, was a product of two gases.

Footage of a candle burning

NARR: … and that fire is not an element but a *process* of combining with oxygen.

Image of cliffs of earth

NARR: Even the solid substances the ancients had lumped under the heading "earth" were now seen in a new way.

Blacksmith painting, then shots of a copper ore and metallic copper behind it.

HISTORIAN ALAN ROCKE, partly in VO

Metals like iron and tin and lead had been known for centuries. But in the era of phlogiston they were thought to be compounds, because they had phlogiston in them. Lavoisier had turned this picture upside down. He showed that by stripping away the oxygen from the ore, you got down to the simpler metal within. The metal, not the ore, was the element.

The four previous images now fill the four quadrants of the screen, and "O" appears in the center.

NARR: So all four of the ancient elements – air, water, earth and fire – had been abolished, thanks to the discovery of oxygen.

ANTOINE LAVOISIER

Once you accept the existence of oxygen, the main difficulties of chemistry appear to evaporate. Well, if all of chemistry can be explained without phlogiston, in all likelihood it doesn't exist.

Priestley pours water in his lab.

NARR: For years, many chemists – including Joseph Priestley – refused to abandon the old theory.

Title page of Traite Elementaire de Chimie

NARR: What finally won the day was the textbook Lavoisier wrote in 1789 to spread his new chemical theory. As it was adopted around the world, phlogiston quietly passed into history.

HISTORIAN SEYMOUR MAUSKOPF

So the old chemical system has been essentially destroyed.

Footage of Lavoisier at his scale, Priestley with his mouse

NARR: Though Lavoisier is often given most of the credit, it was really both these men, working in their very different ways, who brought about this Chemical Revolution.

Priestley shakes his soda water bottle.

BIOGRAPHER STEVEN JOHNSON, partly in VO

They kind of needed each other in a way. For science to work you need both kinds of scientists, right? You need the scientists who are great systematizers, and then you need the mavericks and the tinkerers who are going to open up new doors for discovery.

The two men look out their respective windows.

NARR: One of the doors Priestley and Lavoisier opened was a fresh way to tackle that old question: *What is the world made of?*

Reprise shot of copper ore and metal

NARR: It was clear now that rocks of every conceivable variety might harbor undiscovered elements chemically fused with oxygen.

CHEMIST GREGORY PETSKO

People realized that if they could release oxygen from other substances, what was left behind might be some of these missing elements that everybody knew must be out there.

HISTORIAN ALAN ROCKE

How many more elements might you find by stripping away the oxygen that like to bind to so many things?

Pan up list of "simple substances" in Lavoisier's book

NARR: Lavoisier's textbook included the first modern list of elements – 33 “simple substances.”

CU of "lumière" on Lavoisier's list

NARR: Some, including light and heat, were later found not to be elements. But it was a start, and it served as a challenge to other chemists.

HISTORIAN ALAN ROCKE

Now that they knew how to look for them, chemists began to ask: What *are* the elements? The question had never been asked before in exactly that way. And so the discovery of oxygen really served as a starting gun for a worldwide race for new elements.

Host scene in studio. He pulls down a world map showing the far-flung locations of the discoveries. The names of newfound elements appear on the screen: zirconium, uranium, titanium, yttrium, chromium, beryllium, vanadium, niobium, tantalum, palladium, cerium, osmium, iridium, tellurium, rhodium.

HOST

All over the world, chemists and amateur collectors responded to Lavoisier's challenge, rapidly identifying 15 new elements. From Sweden to Mexico, Connecticut to Siberia, the discoveries kept coming – sometimes as many as four in a single year. And few things could bring a chemist more glory than identifying a new element.

Davy talks with Coleridge, Southey and Cottle. As he holds forth about chemistry, they listen in amazement.

HUMPHRY DAVY

Well, certainly, Lavoisier was one of the great, great masters of all time. In fact, …

NARR: One of those who would soon be caught up in the hunt was a precocious chemist from the farthest reaches of England.

HUMPHRY DAVY

… pathetic ideas of phlogiston, huh?

POET ROBERT SOUTHEY, partly in VO

I've just met a remarkable young man whose talents I can only marvel at. He's not even 21 and has been studying chemistry for no more than 18 months, but he's advanced with such strides as to overtake everybody. His name is Davy … the young chemist … the young everything.

Archival image of young Humphry Davy

NARR: Humphry Davy was the son of a simple wood-carver …

Map showing Penzance's remote location at England's southwestern tip

NARR: … from the remote seaside village of Penzance, about a week from London by stagecoach.

HISTORIAN DAVID KNIGHT, partly in VO

Penzance is right down in the far southwest corner of England, and in some sense it was the Wild West, right out beyond the influence of London and its institutions.

Historic Cornwall images, including apothecary interior

NARR: When his father died young, Humphry left school at 16 and took a job as an apothecary's apprentice to support the family.

Reenactment: 17-year-old Davy reads a book by candlelight.

NARR: But he never lost his love of learning. He simply resolved to teach himself.

Now a CU reveals the book he is reading: Lavoisier's Traite Elementaire de Chimie

AUTHOR RICHARD HOLMES, partly in VO
The same year that Davy's father dies, Lavoisier publishes his *Elementary Treatise on Chemistry*. And young Davy reads this in the original French. He starts keeping notebooks from this very date. And there's a kind of intellectual explosion.

HUMPHRY DAVY, partly in VO
Chemistry arose from the delusions of alchemy, only to be bound by the chains of phlogiston. But through the discoveries of Black, Priestley and Lavoisier, it has now been liberated!

Davy continues reading.

HISTORIAN DAVID KNIGHT VO
Davy started doing experiments right away, and one of the experiments he did was to attack Lavoisier's theory of heat.

AUTHOR RICHARD HOLMES, partly in VO
Lavoisier said it was a material substance called calorique. And Davy didn't believe this.

Davy rubs two pieces of ice together and observes that the friction causes them to melt.

HISTORIAN DAVID KNIGHT, partly in VO
Davy thought he could take on the great man. He thought heat was motion of particles. And he thought he could prove this if he could rub two pieces of ice together – so no heat would be coming in from outside – and the sheer friction would melt the blocks of ice. And that's what happened. To him and his contemporaries, the experiment was a convincing one.

Image of his first work: An Essay on Heat, Light and the Combinations of Light

NARR: Davy's findings, written up in his first published work, showed enough promise …

Map shows path from Cornwall to Bristol, about half the distance to London.

NARR: … to land him a post closer to Britain's center of action, in Bristol …

Photo of the Pneumatic Institution

… at the Pneumatic Institution.

AUTHOR RICHARD HOLMES, partly in VO
So he leaves remote Penzance to become the assistant and then the director of this new institute. He's only 19, for heaven's sake!

Dr. Robert Kinglake detaches a green silk bag from a forge, where it has been filling with gas, and hands it to Davy.

NARR: The institution had been founded in the hope that some of the gases discovered by Priestley and others would prove useful in treating diseases.

Davy inhales a bit of gas and stops to consider the sensation. He flexes his fingers.

NARR: Davy's job was to make the gases – and then test them.

HUMPHRY DAVY, partly in VO
I took just three breaths of the gas. The first produced a feeling of numbness.

NARR: One of the gases he tested was mostly carbon monoxide, the poisonous gas now found in auto exhaust.

Reenactment continues. Davy inhales the gas a second time.

AUTHOR RICHARD HOLMES, partly in VO
He doesn't know exactly what it is, but he makes it. And he tests everything on himself. It is amazingly reckless, but it's also very brave.

The mouthpiece drops from his mouth as Davy slumps over.

PUBLISHER JOSEPH COTTLE, partly in VO
He acted as if in sacrificing one life, he had two or three others in reserve. Some days, I half despaired of seeing him alive the next morning.

Kinglake rouses Davy from unconsciousness and gets him a glass of water. Davy takes his own pulse.

AUTHOR RICHARD HOLMES, partly in VO
And then he takes his pulse, and he says: "*I do not think I shall die."* And he is ill for 48 hours, but he survives. On a number of occasions, he does nearly kill himself.

As Kinglake looks on, concerned, Davy begins to recover.

HISTORIAN DAVID KNIGHT, partly in VO

When you've got a career to make and you're coming from a low point down the social scale, and you've got a long way to go, why not take a few risks, get your way up to the top quicker?

Pan down page in Bristol notebook to reveal: "Davy and Newton"

NARR: The top Davy had in mind was the very pinnacle of science. On one page of his Bristol notebooks, he wrote his own name next to that of the most famous British scientist of all time.

Double portrait of Newton and Davy

AUTHOR RICHARD HOLMES, partly in VO

Newton … and Davy. So he has this sense that he and Newton can go at science together. It's not arrogance exactly. It's this tremendous drive, and he passionately believes that he … will be … a sort of Newton in chemistry.

Davy speaks to his literary friends.

HUMPHRY DAVY

I don't hesitate at all. The great master made a few mistakes.

AUTHOR RICHARD HOLMES VO

All his life, that drive is there: Newton and Davy.

Continuation of first scene with Davy discussing chemistry with the men of letters. Pan of the three men as they're identified in narration.

NARR: In Bristol Davy sought out a group of literary men whose work would define the Romantic Age, including publisher Joseph Cottle … and poets Robert Southey ... and Samuel Taylor Coleridge.

Discussion continues.

HUMPHRY DAVY

... the assumption that heat is a simple substance.

POET SAMUEL TAYLOR COLERIDGE

Is that what he called caloric?

HUMPHRY DAVY

Precisely.

AUTHOR RICHARD HOLMES, partly in VO

In looking at that group in Bristol, one of the things that I think is wonderful: there was no gap between the writers and the poets and the scientists.

Discussion continues.

HUMPHRY DAVY
We can discover that the ice melts by friction alone.

POET ROBERT SOUTHEY
Davy, could not the melting have been caused by the temperature of the room?

HUMPHRY DAVY
That's a very good question, indeed – one to which I have a ready answer. The air …

AUTHOR RICHARD HOLMES, partly in VO
Every evening, they're going out, writing letters to each other, going on walks together. And they are young men with a future. It's an extraordinary group.

NARR: In Davy these Romantic poets found a kindred spirit …

HUMPHRY DAVY
When we remove the ice from the point of friction, it refreezes …

NARR: … a scientist who shared their sense of wonder at Nature and yearned to reveal her mysterious ways.

HUMPHRY DAVY
Heat must, in fact, be the motion of particles.

POET SAMUEL TAYLOR COLERIDGE
There's an energy – an elasticity – in his mind that allows him to seize on and analyze all subjects. Living thoughts spring up like turf under his feet.

Kinglake generates a gas from a tabletop apparatus. Davy sits in the "subject chair" and inhales this gas from a blue silk bag. He feels a "thrilling" sensation.

NARR: Early in his research, Davy produced a gas one medical authority had warned was the cause of terrible diseases. He tried it anyway.

HUMPHRY DAVY, partly in VO
This evening I breathed nitrous oxide and experienced a thrilling all over me – more pleasurable than anything I have ever experienced.

Davy puts the bag down, stamps his feet, laughs uncontrollably, dances around the room.

HUMPHRY DAVY VO

The objects around me became dazzling and my hearing more acute. Sometimes I responded by stamping my feet, other times by dancing around the room and laughing uncontrollably.

Southey tries the gas, considers the sensation.

NARR: As word of his discovery spread, many others – from steam engine pioneer James Watt to the king's own doctor – clamored to try Davy's "laughing gas."

HISTORIAN DAVID KNIGHT, partly in VO

Coleridge and Southey both took doses of the gas. It was very much in keeping with this Romantic time period.

Southey responds to the gas, laughing at Davy and Kinglake.

POET ROBERT SOUTHEY, partly in VO

He's invented a whole new pleasure. It makes you laugh and tingle in every toe and finger-tip.

HISTORIAN DAVID KNIGHT VO

There was a certain amount of recklessness, experimenting with drugs. Why not expand your consciousness?

POET ROBERT SOUTHEY, partly in VO

It makes you strong and happy! So gloriously happy! Oh, excellent airbag. I'm going for more this evening.

Coleridge breathes the gas. Davy watches attentively.

NARR: Davy asked each of his subjects to record their impressions.

Coleridge laughs. Davy takes away the gas bag – you've had enough.

POET SAMUEL TAYLOR COLERIDGE, partly in VO

The first time I tried nitrous oxide, I felt a highly pleasurable sensation of warmth over my whole body. It was like the feeling I once experienced entering a warm room after returning from a walk in the snow. I felt no desire to move – only to laugh at those who were looking at me.

Painting of Davy writing. Image of Davy's book: Researches, Chemical and Philosophical, Chiefly Concerning Nitrous Oxide and its Respiration

NARR: Davy wrote up their accounts in his first true scientific book. But just as he was finishing the book, Davy's attention was diverted by a discovery that would shake the very foundations of science.

Painting of Volta showing his pile to Napoleon

NARR: In 1800, an Italian named Alessandro Volta announced that he had created a new source of electricity.

Image of Franklin harnessing lightning, CU of spark from electrostatic generator, from the Priestley footage. Priestley's son watches, amused.

NARR: Up to then, the only sources of electricity had been lightning, which was very difficult to tap, and electrostatic devices like the ones Priestley had used.

JOSEPH PRIESTLEY (to son)
"How are you doing that?"

HISTORIAN DAVID KNIGHT, partly in VO
You could get quite spectacular effects in the way of flashes and bangs. But you couldn't get sustained power. What Volta did was to establish that electricity was something that you could make a steady supply of – what we call an electric current.

Host scene with voltaic pile and archival image of Volta. Host motions to pile as he describes it.

HOST
Volta's device was incredibly simple – a sandwich of alternating copper and zinc disks, separated by pieces of cardboard that had been soaked in salt water. But the "voltaic pile" – the first battery – electrified the world of science.

HISTORIAN ALAN ROCKE
With the battery, you could now perform a variety of experiments that had never been possible before. And these experiments were done *immediately.*

Host motions to the two inverted test tubes where the hydrogen and oxygen have collected.

HOST
Just weeks after learning of Volta's discovery, two British scientists used a crude battery like this one to split water into its two elements: hydrogen and oxygen.

HISTORIAN DAVID KNIGHT
The electric current was somehow *breaking up* the water into its components.

As the host mentions hydrogen, he removes one tube and inserts a lighted wooden splint. The tube emits a short pop as the hydrogen explodes. He blows out the splint, removes the oxygen tube and inserts the splint. The splint bursts into flame – the same thing we saw in Priestley's lab.

HOST
Even more surprising, the hydrogen collected at the negative electrode over here ... and the oxygen collected at the positive electrode, over here. Why would these two elements show a preference for opposite electrical charges?

Davy begins his first experiment on electricity.

NARR: Intrigued, Davy set aside his research on gases, built a voltaic pile and began doing his own experiments on electricity.

HISTORIAN DAVID KNIGHT VO
And it became Davy's big pursuit in life. What could this electric current do?

HUMPHRY DAVY, partly in VO
Volta has given us a key to some of the most mysterious recesses of nature. Till this discovery, our tools were limited. Now the possibilities for chemistry seem boundless. It's like an undiscovered country – a land of promise.

Davy peers at the bubbles rising in his test vessel.

NARR: Davy had just begun to explore that land when opportunity knocked.

Reprise shot of book

NARR: His book on nitrous oxide had caught the attention of the founders …

Archival image of the Royal Institution on Albemarle Street, ca 1800.

NARR: … of the new Royal Institution in London, who were looking for a director for their chemistry laboratory.

Table of contents showing technical details

AUTHOR RICHARD HOLMES, partly in VO
And that book had such impact that it was read in London, here at the Royal Institution. It's very, very precise. It's measured. It's quantitative science. And they thought, "This is the man we must get."

Painting of Davy. Then, on a map of England, the path from Bristol to London is traced out.

NARR: Still only 22, Davy set out on his next great adventure, leaving Bristol in 1801 for the city he called …

Archival image of London ca 1800

NARR: … "the great hot-bed of human power."

Archival image of young Davy

HISTORIAN DAVID KNIGHT, partly in VO
When Davy arrived, his patrons seem to have been a bit taken aback to find this still rather raw, country youth. But his natural eloquence must have come through and eventually charmed them.

Painting of the RI library

NARR: One of the missions of the institution was to offer public lectures meant to stimulate an interest in science among the London elite.

View of the Royal Institution in 1800

NARR: For this purpose a theater had been installed in the institution's building on Albemarle Street.

James Gillray cartoon showing laughing gas experiments at the RI. Davy, in the background, is highlighted as his position is identified.

NARR: Davy started out as assistant lecturer – seen here helping his boss give a dose of laughing gas to one of the patrons. But with audiences shrinking and the institution's fortunes flagging, Davy was quickly promoted to the top job.

Davy rehearses his lecture as two of his assistants listen.

HUMPHRY DAVY
Nothing is so fatal to the progress of the human mind …

NARR: Determined to make the most of this opportunity, he set out to make each lecture seem spontaneous.

AUTHOR RICHARD HOLMES, partly in VO
But to do spontaneous what he did was prepare, prepare.

HUMPHRY DAVY
… as to suppose that there are no mysteries left in nature.

AUTHOR RICHARD HOLMES, partly in VO
He would read through, in front of his assistants, drafts of the lecture to see if it worked.

HUMPHRY DAVY
Who would not want to learn the most profound secrets of Nature – to ascertain her hidden operations?

AUTHOR RICHARD HOLMES, partly in VO
The moment Davy began to lecture, the audiences packed in.

Exterior of the RI, sound of Davy's voice coming from inside, ramping up under Holmes' bite.

HUMPHRY DAVY VO
Science has done much for man, but it is capable of doing still more.

Huzzahs from the audience

HISTORIAN DAVID KNIGHT
He had people absolutely lapping up what he was pouring out.

Surrey Institute drawing of Davy competitor

NARR: There were other chemists giving public talks elsewhere in London ... but none held a candle to Davy.

Davy rehearses his lecture, eyes flashing, then practices a demonstration.

HISTORIAN DAVID KNIGHT, partly in VO
He must have directed his bright eyes around his audience so that they felt really drawn in and mesmerized. And he would do dazzling experiments that he carefully rehearsed with his assistants the night before, so they always worked.

Image of RI exterior, sounds of delight coming from inside

AUTHOR RICHARD HOLMES VO
And they gasp, they cheer and they clap at the end of a demonstration, it's so brilliantly done.

Drawing showing a carriage-choked Albemarle Street

AUTHOR RICHARD HOLMES, partly in VO
And these lectures became *hugely* popular. And there were terrible traffic jams outside the Royal Institution. Albemarle Street became the first one-way street in London, because there were so many carriages bringing people to listen to his lectures.

Image of attractive young Davy

HISTORIAN ALAN ROCKE, partly in VO
He was young. He was handsome. He was eloquent. And there were a number of young ladies in the audience.

Cartoon close-ups showing ladies in the audience

AUTHOR RICHARD HOLMES, partly in VO

They are all in the front rows making notes, but hanging on Davy's every word. Among the lecture notes in the Royal Institution archive are these little *billets-doux,* little love letters, often signed with a pseudonym, and poems to him!

Archival image of Davy, CU of eyes

NARR: One of his female admirers invited him to dinner, noting: "Those eyes are too fine to be forever gazing over crucibles."

HUMPHRY DAVY

I have audiences of four or five hundred people, many of high rank, and I suspect that some of them may become permanently interested in chemistry. This science is becoming the fashion of the day.

Painting of Davy

NARR: Davy's success as a lecturer and entertainer brought him wealth, prizes, and acclaim. But he was growing impatient. Giving popular lectures was no way to become the Newton of chemistry.

Image of Davy

HISTORIAN DAVID KNIGHT, partly in VO

By 1806 he had established enough of a reputation, and he knew that his work was supporting the Royal Institution. He could say, "Right. I've been doing your work for the last five or six years. Now I'm going to do my own work."

Image of the Royal Society building

NARR: An invitation from an organization once headed by Newton himself gave Davy the perfect chance to show what he could do.

Image of Royal Society room

AUTHOR RICHARD HOLMES, partly in VO

He was asked to lecture not to the Royal Institution but to the Royal Society, the top scientific group in the world. He needed to produce some dramatically original science.

Reprise image of Davy studying his electrical cell in Bristol

NARR: With this goal in mind, Davy dived into the subject he'd been itching to return to ever since Bristol …

Lightning bolt splits the sky in Franklin painting.

NARR: … electricity.

HUMPHRY DAVY
Up to now, we have studied electricity only its most powerful form: lightning. But its slow and silent operations on the earth's surface may prove more important.

Davy watches the bubbles.

NARR: From his early experiments, Davy had learned that an electric current could pry apart the hydrogen and oxygen atoms that made up water.

AUTHOR RICHARD HOLMES
You can use a battery to *un-bond* things and find out what the different elements are.

Davy again looks at Bristol battery.

NARR: That gave Davy an idea: Could he use a bigger battery to tackle substances that were harder to break down?

HISTORIAN ALAN ROCKE, partly in VO
This is something you can do with this new source of electricity. If a small battery gives you a small effect, build a larger one and you get a larger effect.

Page from Davy's notebook, CU of word "potash."

NARR: As the target for his experiment, Davy chose caustic potash …

Images of ash collection pot, then ashes inside the pot

NARR: … a substance derived from wood ashes collected in a pot. Chemists had long suspected it contained an undiscovered element, but no one had been able to break it down into simpler stuff.

AUTHOR RICHARD HOLMES
He believed that if you could apply a charge to it in some way you would discover something about its inner nature.

Davy and his assistant tend his big bank of batteries at the RI

HISTORIAN ALAN ROCKE, partly in VO
So Davy constructed a really big battery because he wanted to see whether potash could be decomposed into its elements.

HISTORIAN FRANK JAMES, partly in VO
Davy was thus able to use the resources of the Royal Institution to undertake scientific research, which had never been the intention of the founders of the RI.

Assisted by his cousin Edmund, Davy carries out his experiments with potash, starting with a watery mix.

NARR: But by the time he began the work, his Royal Society lecture was only a month away.

HUMPHRY DAVY (to assistant)
Shall we?

AUTHOR RICHARD HOLMES VO
He committed himself rather recklessly, because he didn't really have much time.

NARR: Would this new battery be strong enough to reveal what potash was made of?

AUTHOR RICHARD HOLMES VO
Working at top speed, he tries various ways of applying the charge.

Davy checks to see if his experiment is working. His expression tells us it's not.

NARR: Davy first tried putting a current through a mixture of potash and water. All that did was split the water into hydrogen and oxygen ...

HUMPHRY DAVY (to assistant)
Do you see anything?

NARR: ... leaving the potash unaffected.

Now he applies the battery to dry potash, without success.

HISTORIAN DAVID KNIGHT, partly in VO
And then he tried with dried potash, and again, nothing happened.

Now he dampens the potash before connecting the battery. Success! CUs of potassium reacting violently.

NARR: Finally, he moistened the dry potash just a bit before applying the electricity.

HUMPHRY DAVY, partly in VO
Dry potash won't conduct electricity, but when I added a little water and applied a strong electrical current … I soon observed a vivid action. There was a violent effervescence … and small globules.

AUTHOR RICHARD HOLMES
It sweats forth these glowing, shining globules.

CU of the silvery globules

HUMPHRY DAVY, partly in VO
They have a metallic luster very much like mercury, and some of them exploded and burnt with a bright flame. I realized these globules were the substance I had been searching for.

Edmund Davy watches as Humphry performs the experiment.

AUTHOR RICHARD HOLMES, partly in VO
And this is a new element, in fact. It's potassium, one of the crucial elements for life. And he's discovered it. And there's a wonderful description made by his assistant, who was actually Edmund Davy, a young cousin. He said, "The Professor became a boy again."

Davy claps Edmund on the chest in celebration.

EDMUND DAVY, partly in VO
When he saw those globules of potassium burst through the crust of potash and catch fire, he couldn't contain his joy. It was some time before he could compose himself and continue with the experiment.

Davy gradually calms down. CUs of the element he has created.

AUTHOR RICHARD HOLMES, partly in VO
You get the sense of this huge excitement, doing things under pressure, not quite knowing what will happen, whether the damn thing will explode. And then suddenly, the unknown reveals itself.

HISTORIAN DAVID KNIGHT, partly in VO
The atoms of potassium and oxygen, so firmly glued together, could be separated by an electric current in the same way as those oxygen and hydrogen atoms in water.

Page of Davy's notebook. Zoom to "decomp of soda"

NARR: The very next day, Davy used the same method to pull apart caustic soda, or lye, to reveal another new element: *sodium.*

While Edmund and Humphry watch, John Davy cuts potassium into pieces and tosses them into a vessel of water.

HUMPHRY DAVY (to assistants)
Be ready for anything.

NARR: These two new metals were so soft they could be cut with a knife – and so eager to recombine with oxygen that they gave Davy the perfect demonstration for his next lecture.

The potassium fragments skitter across the surface and explode in lavender flames and billows of smoke. The three react with delight.

Exterior of Royal Institution, popping sounds from previous scene, followed by applause from within

NARR: Davy had turned electricity into a powerful tool in the search for new elements.

Over wide shot of Davy working in the lab, the names of four more new elements appear on the screen: magnesium, calcium, strontium and barium.

NARR: The year after discovering potassium and sodium, he used his battery to isolate four more elements.

Over images of other pioneers in electrochemistry appear the names of five other elements they discovered with electricity: boron, iodine, lithium, silicon, aluminum.

NARR: And chemists all over Europe seized on his technique, sending the number of elements even higher.

Shot of Davy's big battery

HUMPHRY DAVY, partly in VO
Sometimes the progress of science is due less to our intellectual powers than to the tools at our disposal. Nothing promotes the advancement of knowledge so much as a new instrument.

Davy and his assistant continue working in the lab.

NARR: Exciting as these discoveries were, in time it would become clear that Davy's greatest contribution was his insight into one of the biggest questions in chemistry.

Return to Bristol electricity scene

HISTORIAN DAVID KNIGHT, partly in VO
Somehow the particles of matter have to be glued together to form molecules. And it was a complete mystery as to what this glue might be. What Davy has had, in effect, is a big idea.

CU of the voltaic pile, Davy in thought

NARR: If electricity could pry apart the atoms in water, potash and soda, might electricity be the force that stuck those atoms together in the first place?

HUMPHRY DAVY
Is electricity an essential property of matter?

Animation: Blobs representing hydrogen and oxygen come together to form water. One is positive, the other negative.

HISTORIAN DAVID KNIGHT VO
Perhaps electricity, with its plus and minus aspects, could be this kind of glue.

HUMPHRY DAVY, partly in VO
In every case that we know of, substances that combine with each other have opposite electrical states. Perhaps this is the reason they're attracted to each other – because opposites attract.

Davy experiments with electricity.

HISTORIAN DAVID KNIGHT, partly in VO
It looked as if electricity might play in chemistry the sort of role that gravity played in Newtonian physics.

Davy statue

AUTHOR RICHARD HOLMES, partly in VO
Remember, he thinks of himself as, on a par in some way with Newton. He is going to be the Newton among chemists. And in a sense, he does eventually achieve that.

Footage of Priestley and his son doing the paper trick with the electrostatic generator

HISTORIAN DAVID KNIGHT VO
In the 18th century, electricity was mostly parlor tricks, like making somebody's hair stand on end and attracting little bits of paper and so on.

Archival image of Davy

HISTORIAN DAVID KNIGHT, partly in VO
Davy showed that electricity is a fundamental aspect of matter. Electricity is what holds us together. It is the glue that links the particles of matter. And, therefore, instead of being rather a side thing, electricity is going to be one of the really central features of science.

Reprise shot of Davy behind host

HOST
It would take more than a century for other scientists to figure out electricity's role. But after Davy, there was no doubt it would be one of the keys to solving the mystery of matter.

Fade to black

Fade up to establishing shot of Dmitri Mendeleev. He gets an idea and reaches for a piece of paper.

VO: Next time on *The Mystery of Matter…*

Mendeleev finds a pattern among the elements.

HISTORIAN MICHAEL GORDIN VO
He figures out something extraordinary about the elements.

DMITRI MENDELEEV, partly in VO
The eye is immediately struck by a pattern – a regular change in the horizontal rows and the vertical columns.

Mendeleev's first Periodic Table is rotated 90 degrees and dissolves into the familiar Periodic Table of the Elements.

AUTHOR ERIC SCERRI VO
He had actually discovered an absolutely fundamental principle of nature.

Marie Curie repeats her measurements again and again.

EVE CURIE VO
My mother made her measurements over again – ten times, twenty times – until she was forced to accept the results.

The results keep coming out the same. Marie looks at Pierre: This is real.

MARIE CURIE VO
I proposed a new term to define this property of matter: radioactivity.

End Credits

Excisable Content Banner: More from *The Mystery of Matter*

Footage of Priestley with the two candles

NARR: Joseph Priestley was the first to publish his discovery of the remarkable gas we call oxygen.

Screen splits to make room for footage of Lavoisier at his scale.

NARR: Antoine Lavoisier was the first to understand its true significance.

Screen splits again and outline of mystery man appears alongside the others.

NARR: But there's a third man in the oxygen story.

The outline fills in with an image of Scheele.

NARR: a Swedish apothecary named Carl Wilhelm Scheele.

HISTORIAN SEYMOUR MAUSKOPF, partly in VO
... who is also rather like Priestley, a wonderful experimentalist. In fact, he made the discovery before Priestley did, possibly as early as 1771.

Composite image of Scheele's book and his tardy mentor, Torbern Bergman

NARR: But when he discovered the gas he called "fire air," Scheele decided to publish his results in a book – and waited years for his mentor to write the preface.

CHEMIST ROALD HOFFMANN, partly in VO
The book doesn't get published till 1777, by which time all the chemists of Europe had already heard about Priestley's and Lavoisier's work.

Four elements are highlighted in the Periodic Table: chlorine, manganese, barium and molybdenum

NARR: While Scheele's discovery of oxygen had no impact on the course of science, he did go on to have a hand in the discovery of four more elements.

CHEMIST GREGORY PETSKO
… and got zero credit for this. First of all, he was a pharmacist and nobody paid any attention to him. Second, he was working in Sweden, and most of the scientific world paid zero attention to what was happening in Sweden. And third, he had the misfortune to die rather young as a result of his own experiments. He was constantly sniffing terrible chemical substances and was eventually found dead at his desk with so many toxic materials around him that to this day, nobody has any idea exactly what he died of.