

Four five-minute physics plays

The showing-off edition

Four speaking parts each. No props, though a lab coat and a terrible accent never hurt anybody. About five minutes if you don't milk it — seven if you do, and you probably will.

Notes for performers. Every part has at least one moment built in for showing off: a big line, a long pause, or a chance to be gloriously annoying. Take them. Lines marked *(to the audience)* are said straight out front while the others pretend not to hear.

The people and the science are real. The dialogue is invented, except where the footnotes say otherwise.

1. The Gold Foil

4.4 Atomic structure · Manchester, 1909

Characters

- **RUTHERFORD** — enormous voice, enormous moustache, no indoor volume setting
- **GEIGER** — precise, deadpan, has seen everything
- **MARSDEN** — twenty years old, terrified, correct
- **THOMSON** — very grand, very dry, enjoys this far more than he should

RUTHERFORD	<i>(bellowing from off)</i> GEIGER!
GEIGER	<i>(not looking up)</i> He is in the building.
RUTHERFORD	<i>(entering)</i> GEIGER! How are my alpha particles?
GEIGER	Behaving themselves, Professor. We fire them at the gold foil. They go straight through. They land exactly where we expect. It is the least surprising thing in Manchester.
RUTHERFORD	As it should be! Thomson's model says the atom is a soft pudding of positive charge with electrons stuck in it like currants. An alpha particle goes through a pudding like a cannonball through a cloud.
GEIGER	Professor, this is Marsden. He is an undergraduate. He needs a project.
MARSDEN	<i>(far too eagerly)</i> Good morning sir it's an honour sir I've read all your papers sir —
RUTHERFORD	Have you read them, or have you <i>held</i> them?
MARSDEN	...Mostly held, sir.
RUTHERFORD	Honest. I like that. Very well, Marsden. Here is your project. I want you to look for alpha particles coming <i>backwards</i> .
MARSDEN	Backwards?
RUTHERFORD	Off the foil. Back towards the source.
MARSDEN	But sir, that's —
RUTHERFORD	Impossible. Yes. Completely impossible. You will find nothing, you will learn to use the apparatus, and you will discover the deepest rule of science: <i>check the things you are certain of</i> . Off you go. <i>(RUTHERFORD sweeps out. A silence.)</i>
MARSDEN	He wants me to spend six weeks finding nothing.
GEIGER	Welcome to research. <i>(Time passes. MARSDEN counts under his breath, increasingly agitated.)</i>

MARSDEN Four. Five. ...Six. Dr Geiger.

GEIGER Mm.

MARSDEN Dr Geiger.

GEIGER Mm.

MARSDEN DR GEIGER.

GEIGER (*looking up at last*) You have the face of a man who has broken something expensive.

MARSDEN They're coming back.

GEIGER What are?

MARSDEN The alpha particles. Not deflected a bit — turned *right round*. About one in eight thousand. I have counted them four times.

GEIGER That is impossible.

MARSDEN (*slightly hysterical*) I KNOW it's impossible. I counted them ANYWAY.

GEIGER (*standing, suddenly very alert*) Count them again. I shall fetch the volume.

MARSDEN The what?

GEIGER The Professor.

(*RUTHERFORD enters at speed.*)

RUTHERFORD WELL?

MARSDEN (*tiny*) Some of them bounce, sir.

RUTHERFORD (*long, long pause — milk it*) It was... quite the most incredible thing that has ever happened to me. It is as if you had fired a fifteen-inch shell at a sheet of tissue paper — and it came back and hit you.

MARSDEN Have I done it wrong, sir?

RUTHERFORD You have done it perfectly. It is the *universe* that has done it wrong. Think, boy. Most go straight through. Therefore?

MARSDEN The atom is mostly empty space.

RUTHERFORD Some are nudged aside. Therefore?

GEIGER Something positive in there, repelling them.

RUTHERFORD And a very few come *straight back*. Therefore?

MARSDEN It's... tiny. And heavy. Heavy enough to stop an alpha particle dead and send it home again.

RUTHERFORD A *nucleus*. All the positive charge, nearly all the mass, in a space ten thousand times smaller than the atom. (*to the audience, gleefully*) And the pudding is cancelled.

GEIGER Thomson will be furious. The pudding is his.

RUTHERFORD Thomson is a better man than his pudding.

(*THOMSON enters. Everyone straightens up.*)

THOMSON I understand my dessert is in difficulty.

MARSDEN (*squeaking*) I'm very sorry, sir.

THOMSON Sorry? Young man, you have ruined twenty years of my work in an afternoon. (*beat*) It is the nicest thing anyone has done for me all year. Show me the numbers.

MARSDEN Four runs, sir. And Dr Geiger repeated them after me.

THOMSON	<i>(reading, nodding slowly)</i> Repeated. Good. <i>(handing it back)</i> Then the model changes. That is not a defeat. That is the entire point of the method. Any fool can have a theory. It takes a scientist to let one go.
RUTHERFORD	It still isn't finished. The nucleus is far too heavy for the protons alone. There is something else in there. Something with no charge at all.
GEIGER	How would we ever detect something with no charge?
RUTHERFORD	We shan't. Chadwick will. <i>(to the audience)</i> Give him twenty years.
MARSDEN	<i>(to the audience)</i> He was out by one.

Discuss

1. Three observations, three conclusions. Say all six.
2. Why ask a student to look for something you're certain isn't there?
3. Thomson was wrong. Was Thomson a bad scientist?

Rutherford's "fifteen-inch shell" line is very close to what he actually said. Chadwick found the neutron in 1932 — twenty-one years later.

2. The Expanding Sky

4.8 Space physics • 1929

Characters

- **HUBBLE** — American, but puts on an English accent because he thinks it sounds cleverer. Smokes a pipe he doesn't need.
- **SLIPHER** — did most of the hard work, gets none of the credit, mentions this
- **LEMAÎTRE** — a Catholic priest *and* a physicist, unfailingly gentle, quietly demolishes everybody
- **HOYLE** — Yorkshire, blunt, enjoys an argument the way other people enjoy lunch

SLIPHER	Hubble. Forty galaxies. Spectra for every one. It took me <i>years</i> .
HUBBLE	(<i>very grand</i>) How frightfully good of you, old chap.
SLIPHER	You're from Missouri.
HUBBLE	(<i>unbothered</i>) Show me the spectra.
SLIPHER	Every absorption line is in the wrong place. The same hydrogen pattern we get in the lab — but shifted. Towards the red. Every time.
HUBBLE	Longer wavelength means the source is moving away. They're running from us.
SLIPHER	All but Andromeda. Andromeda is coming <i>at</i> us.
HUBBLE	Andromeda is practically a neighbour. Ignore Andromeda.
SLIPHER	That's what everyone says about me.
HUBBLE	Give me your speeds. I have the distances. (<i>scribbling</i>) Speed against distance... and... (<i>He stops. Removes pipe. Stares.</i>)
SLIPHER	What?
HUBBLE	It's a straight line.
SLIPHER	It's never a straight line. Nothing in astronomy is a straight line.
HUBBLE	Twice as far, twice as fast. (<i>to the audience, dropping the accent entirely</i>) Oh, that's beautiful. (<i>accent back on</i>) I mean — how pleasing.
SLIPHER	Hang on. If everything's running away from us — are we the centre of the universe?
HUBBLE	(<i>uneasily</i>) We are in Pasadena.
LEMAÎTRE	(<i>entering</i>) You are not the centre of anything. May I? Imagine a balloon, with dots inked on the surface. Now blow it up. What do the dots do?
SLIPHER	Move apart.
LEMAÎTRE	Stand on one dot. What do the others do?
SLIPHER	Run away from me. And the far ones faster, because there's more rubber stretching in between. (<i>beat</i>) Oh.
LEMAÎTRE	Which dot is the centre of the surface?
SLIPHER	None of them.
LEMAÎTRE	It is not galaxies flying through space. It is space itself expanding, and carrying them.
HUBBLE	I am an <i>observer</i> , Father. I measure. I leave the wild speculation to priests.

LEMAÎTRE How kind. Then let me speculate wildly. If everything is further apart today than yesterday — what about the day before? And before that? Run your film backwards far enough, Dr Hubble, and everything in the universe is in one place. Hot. Dense. And then —

(He makes a small, polite gesture of explosion.)

HOYLE *(entering, loudly)* Absolute rubbish.

LEMAÎTRE Good afternoon, Mr Hoyle.

HOYLE A priest. Proposing a moment of creation. Forgive me if that seems a bit convenient.

LEMAÎTRE *(mildly)* My religion is not the argument. The red-shift is the argument. Argue with the red-shift.

HOYLE I agree with the red-shift! Expanding, fine. But why must it have *started*? My universe expands for ever, new matter trickles in to fill the gaps, it looks the same in every age. A steady state. No beginning. Nothing to explain.

HUBBLE Gentlemen. Both your theories fit my graph exactly. So what separates them?

HOYLE A prediction. One of us must predict something the other doesn't.

LEMAÎTRE Then here is mine. If the early universe was unimaginably hot, where did that heat go? Nowhere. It is still travelling. By now the expansion will have stretched it to very long wavelengths. Microwaves. A faint glow, from every direction in the sky, with nothing in particular producing it.

HOYLE My theory predicts no such thing.

LEMAÎTRE I know. That is rather the point.

HOYLE *(grudgingly)* ...That's a proper prediction, that.

LEMAÎTRE Thank you.

HOYLE I'm still calling it your "big bang".

LEMAÎTRE Call it whatever amuses you. Only go and *look*.

HOYLE *(to the audience)* I called it the Big Bang to make it sound daft. *(beat)* It is now the official name. For ever. *(beat)* I'd like that on the record.

In 1964 two engineers found a hiss in their aerial they could not get rid of. They cleaned out the pigeons. The hiss stayed. It was the cosmic microwave background — from every direction in the sky, exactly as predicted.

Discuss

1. Why doesn't red-shift in all directions put us at the centre?
 2. Both theories explained the red-shift. What decided it?
 3. Hoyle was wrong. Was he useful?
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3. The Current War

4.2 Electricity · New York, 1888

Characters

- **EDISON** — grumpy, deaf when it suits him, has invested everything in being right
- **TESLA** — immaculate, fastidious, counts things, fonder of pigeons than of Edison
- **WESTINGHOUSE** — cheerful businessman, says nothing he can't sell
- **NELLIE** — reporter. Writes everything down. Especially the bits they regret.

NELLIE	Mr Edison. My readers want to know why their street is a hole.
EDISON	Because I am <i>lighting</i> it, madam. Direct current. Same as a battery. Always one way. Steady, simple, safe.
NELLIE	And the hole?
EDISON	Cables. And a generating station every mile.
NELLIE	(<i>writing</i>) Every... mile.
EDISON	Say it like that and you make it sound bad.
NELLIE	I wrote it down exactly as you said it.
EDISON	That's the problem with reporters.
TESLA	(<i>entering, brushing the chair before sitting</i>) It is every mile because he sends it at low voltage, which means an enormous current, which means the cables get hot and the lamps at the far end go dim.
EDISON	You used to work for me.
TESLA	I did. You promised me fifty thousand dollars and then explained that it was an American joke. (<i>beat</i>) I did not laugh then either.
NELLIE	Mr Tesla. Explain the current. Simply. I have six hundred words and most of my readers are eating breakfast.
TESLA	Power equals potential difference times current. You wish to deliver a fixed power to the lamps. You may do it with a high voltage and a <i>small</i> current, or a low voltage and a <i>large</i> current. Mr Edison has chosen large.
NELLIE	And?
TESLA	The energy wasted heating the cable depends on the current <i>squared</i> . Double the current — four times the waste. Ten times the current —
NELLIE	A hundred times the waste.
TESLA	(<i>delighted</i>) She can multiply! Mr Edison, she can multiply.
EDISON	I heard.
WESTINGHOUSE	(<i>entering, booming</i>) So we send it at thousands of volts, the current is tiny, the cables stay cool, and one station serves a whole state. Westinghouse Electric. Card?
NELLIE	Thousands of volts. Into people's <i>houses</i> .
WESTINGHOUSE	Good heavens, no. We step it down to something safe before it gets anywhere near a house.
NELLIE	How?

TESLA A transformer. Two coils on an iron core. But — and this is the part Mr Edison cannot escape — a transformer needs a *changing* magnetic field to induce anything in the second coil. Alternating current changes direction sixty times a second, so the field is always changing, so it works.

WESTINGHOUSE And direct current?

TESLA Steady current. Steady field. Nothing changes, so nothing is induced, so nothing happens. *(to EDISON, with great politeness)* It is not that you are foolish. It is that you are fighting physics, and physics does not get tired.

EDISON High voltage *kills people*.

WESTINGHOUSE So does a gas lamp and a dry curtain.

EDISON I intend to *demonstrate* the danger. Publicly. With animals.

TESLA *(flatly)* You intend to electrocute a horse in front of newspaper reporters.

NELLIE *(writing very fast)* Would you say that again a little slower?

EDISON Don't write that down.

NELLIE Too late, it's lovely.

TESLA Mr Edison, that is not an argument about engineering. That is theatre.

EDISON *(after a pause)* Everything I own is direct current. Every patent. Every station. Every cable under that street.

TESLA *(gently, for once)* Yes. And that is the real argument, isn't it.

WESTINGHOUSE Miss, there's a decision coming. Niagara Falls. They must power Buffalo — twenty miles away.

NELLIE Twenty miles. Mr Edison, can direct current reach Buffalo?

EDISON *(very long pause)* ...Not without a station every mile.

NELLIE That's twenty stations.

EDISON I can count, madam.

NELLIE Mr Tesla?

TESLA Step it up at the falls. Twenty miles at high voltage, current so small the cables barely warm. Step it down in Buffalo. *(beat)* Tuesday.

NELLIE *(closing notebook)* I have my headline.

EDISON You might also print that I electrified the first city on Earth.

NELLIE *(kindly)* I'll print that too, Mr Edison. Both things can be true. *(to the audience)* It made a *terrible* headline though.

Niagara chose alternating current in 1893. Every National Grid on Earth now does exactly what Tesla described: step up, transmit, step down.

Discuss

1. Why does high transmission voltage waste less? Use $P = VI$ and $P = I^2R$.
 2. Why won't a transformer work on direct current?
 3. Edison had the better safety argument and lost anyway. Why?
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4. Beyond the Red

4.6 Waves • 1800, then 1887

Characters

- **WILLIAM HERSCHEL** — obsessive, absolutely will not stop
- **CAROLINE HERSCHEL** — his sister, a serious astronomer, has had quite enough
- **MAXWELL** — Scottish, so excited by his own equations he can barely sit down
- **HERTZ** — German, magnificently unimpressed by his own discovery

CAROLINE	William. You have been staring at a prism for one hour and forty minutes.
HERSCHEL	I am being thorough.
CAROLINE	You are being <i>peculiar</i> .
HERSCHEL	When I look at the sun through coloured filters, some of them scorch my eye and some do not. I wish to know which colour carries the heat.
CAROLINE	So you split the sunlight into a rainbow and put a thermometer in it.
HERSCHEL	Precisely. Read them out.
CAROLINE	Violet, slightly warm. Green, warmer. Yellow, warmer. Red — the warmest.
HERSCHEL	So heating increases from violet across to red. A clean result.
CAROLINE	Lovely. Dinner?
HERSCHEL	Move the thermometer past the red.
CAROLINE	Past the red? William, there's <i>nothing</i> past the red. The rainbow has finished. That's the end. That's just table.
HERSCHEL	Then it will read the temperature of the room, and that will prove our other readings are sound. A control.
CAROLINE	(<i>sighing, moving it</i>) Fine. One control. And then dinner. (<i>A pause. She looks. She looks again. She picks the thermometer up and looks at it very closely.</i>)
CAROLINE	William.
HERSCHEL	Mm.
CAROLINE	It's the hottest one.
HERSCHEL	Don't be absurd.
CAROLINE	<i>Hotter than the red.</i> In a place where there is NO LIGHT AT ALL.
HERSCHEL	(<i>crossing slowly</i>) Read it again.
CAROLINE	I have read it three times. It is sitting in the dark, next to nothing, getting warm.
HERSCHEL	Then something is <i>arriving</i> there. Something beyond the red, invisible to the eye, carrying energy.
CAROLINE	Light you cannot see is a contradiction in terms.
HERSCHEL	Only if we let the eye decide what exists. (<i>to the audience</i>) And the eye, frankly, is a <i>terrible</i> instrument.
CAROLINE	What do we call it?
HERSCHEL	Infra-red. Below the red. (<i>beat</i>) Caroline. If there is something past one end of the spectrum —
CAROLINE	No.

HERSCHEL — what is past the *other*?

CAROLINE (*to the audience*) We did not have dinner.

(*Sixty years pass. The Herschels stay put. MAXWELL bursts in.*)

MAXWELL There IS something past the other end and I found it WITHOUT LEAVING MY DESK!

HERSCHEL Who —

MAXWELL Maxwell. Scotland. Equations. Listen: a changing electric field creates a magnetic field. A changing magnetic field creates an electric field. Each one keeps making the other, over and over, and the pair of them go *tearing off across the room as a wave*.

CAROLINE At what speed?

MAXWELL (*stopping dead*) Ah. Yes. That. That's the bit where I had to sit down. The equations give you the speed. And the speed they give you is... the measured speed of light.

HERSCHEL So light is an electromagnetic wave.

MAXWELL Light is an electromagnetic wave. And so is your infrared. And so are waves *metres* long that nobody has ever detected, because nobody has gone and looked.

HERTZ (*entering, deadpan*) I looked.

MAXWELL And?

HERTZ I made a spark jump a gap. Across the room I put a loop of wire with its own tiny gap, connected to nothing whatsoever. When my spark jumped — a spark jumped in the loop.

CAROLINE Through the air? With no wire between them?

HERTZ The oscillating current made a wave. The wave crossed the room. The wave made the electrons in the loop oscillate, which induced a voltage, which made the second spark. Exactly as the equations said.

MAXWELL (*ecstatic*) HA!

HERSCHEL And what is it *for*?

HERTZ (*shrugging*) Nothing. It is of no use whatsoever. It is simply an experiment that proves Maestro Maxwell was right.

(*A pause. HERSCHEL and CAROLINE turn slowly to the audience.*)

HERSCHEL (*to the audience*) Every radio.

CAROLINE Every television.

HERSCHEL Every telephone in every pocket in this room.

HERTZ (*still deadpan*) No use whatsoever.

CAROLINE (*to HERSCHEL*) He put a thermometer where there was nothing and found the infrared. You made a spark and found the radio wave. Neither of you had the faintest idea what you'd done.

HERSCHEL (*happily*) That is rather the point of looking.

CAROLINE (*to the audience*) And *still* no dinner.

Discuss

1. Why did Herschel put the thermometer beyond the red at all?
2. What do all electromagnetic waves have in common?
3. Hertz thought his discovery was useless. Should scientists only work on useful things?

The science and the people are real; the dialogue is invented. Three things actually happened: Rutherford's fifteen-inch shell remark, Hertz saying his discovery had no use whatsoever, and Hoyle coining "Big Bang" to mock a theory that then kept the name. Caroline Herschel really was an astronomer in her own right, and discovered eight comets.

5. The Cannon and the Horses

4.3 Particle model · Munich, 1798

Characters

- **COUNT RUMFORD** — born Benjamin Thompson in Massachusetts, now a Count because he asked to be. Immensely pleased with himself.
- **FOREMAN KELLER** — runs the cannon workshop, has done this for thirty years, does not want a Count in his workshop
- **DR WEBER** — defender of caloric, the official theory, increasingly desperate
- **ANNA** — the workshop's water-carrier, says almost nothing until it matters

KELLER	Your Excellency, with respect, this is a <i>cannon workshop</i> .
RUMFORD	I am aware.
KELLER	Men are boring out cannon barrels. Horses turn the drill. It is loud, it is filthy, and nothing of interest has ever happened in it.
RUMFORD	On the contrary. Something <i>extraordinary</i> happens in it every single day and nobody has bothered to look. Keller — when you bore a cannon, what comes out?
KELLER	Brass shavings. And heat. Terrible heat. We keep the barrel in water or you cannot touch it.
RUMFORD	And where does the heat come from?
KELLER	(<i>as if to an idiot</i>) From the drilling.
RUMFORD	Dr Weber. Where does the heat come from?
WEBER	From the <i>caloric</i> , naturally. Caloric is an invisible fluid of heat contained inside every substance. Grinding the brass into shavings squeezes the caloric out of it. Everybody knows this.
RUMFORD	Then I have two questions and I have been looking forward to both. First — if the caloric is squeezed <i>out</i> of the shavings, the shavings must be changed. Keller, are the shavings different from the brass?
KELLER	They're brass. Smaller, but brass. Same weight, heat them the same, behave the same.
WEBER	...A <i>subtle</i> change.
RUMFORD	Second question. Bring the blunt borer.
KELLER	The blunt one cuts nothing. It just rubs.
RUMFORD	Exactly so. Run it. (<i>Rumbling. Time passes.</i>)
KELLER	Two and a half hours, Excellency. It has produced almost no shavings at all.
RUMFORD	And the water round the barrel?
KELLER	(<i>pause</i>) Boiling. (<i>beat</i>) It's boiling. Without a fire. I've worked here thirty years and I have never once seen the water boil without a fire.
RUMFORD	(<i>to the audience, delighted</i>) And there is the whole of thermodynamics in a bucket.
WEBER	This proves nothing. The caloric is simply being released more... gradually.
RUMFORD	From shavings that do not exist? Dr Weber, the horses have been walking in a circle for two and a half hours. The heat has not stopped. It will not stop. Keep the horses walking and the water will keep boiling until the horses drop. How much caloric is in that barrel?
WEBER	A... great deal.

RUMFORD	An <i>infinite</i> amount? A finite lump of brass containing an endless supply of fluid? Can a thing contain more than everything?
WEBER	(<i>quietly</i>) No.
RUMFORD	Then it is not a fluid in the brass. It is coming from somewhere else. It is coming from the <i>horses</i> . From the work being done. Motion, turning into heat, and never running out as long as somebody keeps pushing. Heat is not a substance at all. Heat is motion.
WEBER	The motion of what?
RUMFORD	(<i>a pause — caught out</i>) ...Of the little parts of the brass. The particles. Vibrating harder. (<i>beat</i>) I cannot see them, so I cannot prove it. But that is what it must be.
ANNA	(<i>who has been carrying water the whole time</i>) Can I say something?
KELLER	Anna, not now —
RUMFORD	Let her.
ANNA	I carry the water. Four buckets, every hour, all day. And at the end of the day my arms ache and the buckets don't. (<i>beat</i>) If the heat came out of the brass, I'd be getting colder. I'm not. I'm exhausted. The heat's coming out of <i>me</i> . (<i>A long silence.</i>)
RUMFORD	(<i>to the audience</i>) It took me nine pages of Latin to say that.
KELLER	She also noticed the blunt borer, Excellency. Three years ago. She mentioned it to me and I told her to get on with the water.
ANNA	You did.
KELLER	(<i>to the audience</i>) And I will be hearing about it for the rest of my life.

Discuss

1. What two pieces of evidence killed the caloric theory?
2. Why does "the heat never runs out" matter so much to Rumford's argument?
3. Rumford could not see particles. Was he right to say they were there anyway?

Rumford really did bore cannon with a blunt borer and boil water without fire, and it really did help kill the caloric theory. Keller, Weber and Anna are invented.

6. The Twitching Needle

4.7 Magnetism · Copenhagen 1820, then London

Characters

- **HANS CHRISTIAN ØRSTED** — mid-lecture, Danish, a showman who has lost control of his own demonstration
- **A STUDENT** — front row, sharp-eyed, ruins everything
- **MICHAEL FARADAY** — was a bookbinder's apprentice, never went to university, knows it, uses it
- **SIR HUMPHRY DAVY** — Faraday's boss. Famous. Does not enjoy being overtaken.

ØRSTED	— and so, ladies and gentlemen, when I close the switch, the wire will carry a current, and the wire will become warm. That is all. That is the whole demonstration. Electricity and magnetism are entirely separate phenomena and anyone who tells you otherwise is selling something. <i>(He closes the switch.)</i>
STUDENT	Sir.
ØRSTED	Not now.
STUDENT	Sir, the compass moved.
ØRSTED	The compass is on the bench for storage. Ignore the compass.
STUDENT	It moved when you closed the switch.
ØRSTED	<i>(not turning round)</i> Coincidence.
STUDENT	Open it again.
ØRSTED	I am lecturing.
STUDENT	<i>Open it again.</i> <i>(A pause. ØRSTED opens the switch.)</i>
STUDENT	It swung back.
ØRSTED	<i>(very slowly turning round)</i> ...Say that again.
STUDENT	When the current flows, the needle swings. When it stops, the needle swings back. Sir — the current is making a magnetic field.
ØRSTED	That is not possible. I have just told two hundred people it is not possible. <i>(closes switch)</i> ...It swings.
STUDENT	It swings.
ØRSTED	<i>(opens)</i> It returns. <i>(closes)</i> It swings. <i>(to the audience, faintly)</i> Twenty years I have taught that these two things have nothing to do with one another, and a boy in the second row has just —
STUDENT	Third row.
ØRSTED	<i>(dangerously)</i> Third row. <i>(beat, then genuine delight)</i> An electric current produces a magnetic field around the wire! In circles! That is an entirely new fact about the universe and it happened in front of everybody. <i>(to the audience)</i> Write to the journals. Write to all of them.
 <i>(London. FARADAY reading. DAVY behind him.)</i>	
FARADAY	Sir Humphry, have you read Ørsted?
DAVY	A Dane and a twitching needle. Everyone has read Ørsted.
FARADAY	A current makes a magnetic field. So I have been asking the obvious question for ten years and nobody will answer it.

DAVY	Which is?
FARADAY	<i>Can you do it backwards?</i> If electricity makes magnetism — can magnetism make electricity?
DAVY	Many have tried. They put a magnet near a coil, they connect a meter, they wait. Nothing happens. It is a dead end, Faraday. Leave it.
FARADAY	They put the magnet near the coil and they <i>wait</i> .
DAVY	Yes.
FARADAY	That's it. That's the mistake. (<i>standing</i>) They're leaving it still.
DAVY	And?
FARADAY	Watch. Magnet. Coil. Meter. Magnet sitting inside the coil — nothing, exactly as you say. Now watch the needle while I <i>push the magnet in</i> .
DAVY	(<i>despite himself</i>) It kicked.
FARADAY	Now I hold it still inside.
DAVY	Nothing.
FARADAY	Now I pull it out.
DAVY	It kicked the other way. (<i>beat</i>) Do it again.
FARADAY	(<i>doing it</i>) In. Still. Out. In. Still. Out.
DAVY	It only works while it's <i>moving</i> .
FARADAY	It isn't the magnetic field that induces a voltage. It's the <i>change</i> in the magnetic field. A steady field does nothing at all. Everyone before me was holding it perfectly still and concluding there was nothing to find.
DAVY	(<i>grudging</i>) And faster?
FARADAY	Faster, bigger kick. Stronger magnet, bigger kick. More turns on the coil, bigger kick. (<i>to the audience</i>) Every power station on Earth is this, made large, with something else turning the handle.
DAVY	You have no mathematics for it.
FARADAY	I have no mathematics at all, sir. I was a bookbinder. I have the apparatus and I have the result, and someone cleverer than me can write it down in symbols.
DAVY	(<i>to the audience, sourly</i>) I discovered a great many things in my life. I have been told repeatedly that my greatest discovery was Michael Faraday. (<i>beat</i>) I would like it minuted that I find that remark extremely irritating.

Discuss

1. What is the one word that makes the generator effect work? (*Change.*)
2. Why did everybody before Faraday fail?
3. Ørsted was proved wrong mid-lecture by a student. How should a scientist react to that?

Ørsted really did notice the effect during a lecture. Faraday really was an apprentice bookbinder with no formal mathematics, and the remark about Davy's greatest discovery is a genuine piece of Victorian gossip.

7. The Honeymoon Thermometer

4.1 Energy · Manchester and the Alps, 1847

Characters

- **JAMES JOULE** — brewer by trade, physicist by obsession, no sense of occasion whatsoever
- **AMELIA JOULE** — his wife. On her honeymoon. Patient, but there are limits.
- **WILLIAM THOMSON** — young, brilliant, about to become Lord Kelvin, currently just nosy
- **A WAITER** — Swiss, has seen tourists do many things, has not seen this

AMELIA	James. We are in the Alps. On our honeymoon. There is a waterfall.
JOULE	I know! Isn't it marvellous?
AMELIA	It is.
JOULE	<i>(producing an enormous thermometer)</i> I've brought the long one.
AMELIA	...The long what?
JOULE	Thermometer. Specially made. Reads to a fiftieth of a degree.
AMELIA	Why is there a thermometer on my honeymoon?
JOULE	Because of the waterfall! Amelia — the water at the top has gravitational potential energy. It falls. On the way down that becomes kinetic energy. And when it smashes into the rocks at the bottom, where does the energy go?
AMELIA	Away?
JOULE	Energy does not go away! That's the entire point! It must still be there, as heat. The water at the bottom of a waterfall must be <i>warmer</i> than the water at the top.
AMELIA	By how much?
JOULE	<i>(beaming)</i> Hardly anything! A few hundredths of a degree! Which is why I've brought the long one!
AMELIA	<i>(to the audience)</i> I knew what I was marrying. <i>(beat)</i> I did not know it was coming on the honeymoon.
WAITER	<i>(approaching)</i> Monsieur. You are standing in the waterfall.
JOULE	I'm taking the bottom reading.
WAITER	You are wearing a suit.
JOULE	I am. Could you hold this?
WAITER	<i>(taking it)</i> ...Oui.
THOMSON	<i>(entering)</i> I say — are you James Joule?
AMELIA	He is in the waterfall.
THOMSON	I know your paper. The paddle wheel. You put a paddle in water and churned it with falling weights and the water got warmer.
JOULE	<i>(from the water)</i> It did! And the amount of warming was always in exactly the same proportion to the work done by the weights! Always! Every time! Mechanical work and heat are the same currency!
THOMSON	Nobody at the Royal Society believed you.
JOULE	Nobody at the Royal Society has ever run a brewery. In a brewery, young man, a tenth of a degree is money. I measure small things for a <i>living</i> .

THOMSON	(to the audience) He read a paper in Oxford and there was no discussion at all afterwards. None. The room simply moved on to the next item. (beat) He was right and the room was wrong, and the room never apologised.
AMELIA	James. What does the thermometer say?
JOULE	(climbing out, soaked) Bottom of the fall. Now the top. (beat) Amelia — it's warmer at the bottom.
AMELIA	By how much?
JOULE	Hundredths of a degree. Exactly as predicted. (to THOMSON) Do you understand what that means? The energy was never lost. It was never destroyed. It went from gravitational, to kinetic, to heat, and the books balance all the way down.
THOMSON	Conservation of energy.
JOULE	Conservation of energy. In a Swiss waterfall. On my honeymoon.
THOMSON	(to the audience) I spent the rest of my career working with that man.
AMELIA	(firmly) Right. The thermometer goes in the case, the case goes in the trunk, and we are going to look at the waterfall like normal people.
JOULE	For how long?
AMELIA	Ten minutes.
JOULE	(delighted) Ten whole minutes!
WAITER	(to the audience, still holding the thermometer) They came back the next day. He brought a second thermometer.

Discuss

1. Trace the energy from the top of the waterfall to the bottom.
2. Why would warming of only hundredths of a degree still prove his point?
3. Joule was ignored by the Royal Society for years. Why might experts resist a new idea?

Joule really did take a thermometer on his honeymoon to measure a waterfall, and really did run his family's brewery. Thomson really did meet him on that trip and became his collaborator.

8. Two Balls and a Church Lamp

4.5 Forces • Pisa, around 1590

Characters

- **GALILEO GALILEI** — 26, insufferable, correct
- **PROFESSOR BORRO** — teaches Aristotle, has taught Aristotle for forty years, will go on teaching Aristotle
- **VINCENZO** — a student, caught between them, enjoying it enormously
- **SISTER CLARA** — keeps the cathedral. Knows exactly what Galileo is doing in there.

BORRO Aristotle is perfectly clear. Heavier objects fall faster. A ten-pound weight falls ten times as fast as a one-pound weight. This has been the settled view for nineteen hundred years.

GALILEO And has anybody dropped them?

BORRO I beg your pardon?

GALILEO In nineteen hundred years. Has anybody actually gone up a tower and dropped two things?

BORRO One does not need to. Aristotle reasoned it.

GALILEO Then let me reason too. Professor — if I tie the heavy ball to the light ball with a short string, what do I have?

BORRO Two balls on a string.

GALILEO And what do I *also* have?

BORRO ...One heavier object.

GALILEO Good. Now. Aristotle says the light ball falls slowly. So as they fall, the light ball must drag on the heavy one and *slow it down*. The pair falls slower than the heavy ball alone.

VINCENZO That follows.

GALILEO But the pair together is *heavier* than the heavy ball alone. So by Aristotle it must fall *faster*.

BORRO ...

GALILEO Slower and faster. The same objects. The same theory. *(to the audience, insufferably)* And I did that without leaving the room.

VINCENZO *(enjoying this far too much)* Professor, which is it?

BORRO It is more subtle than —

VINCENZO Slower or faster?

BORRO *(to VINCENZO)* You are not helping yourself.

VINCENZO No, Professor, but I am having a lovely morning.

GALILEO The theory contradicts itself, so the theory is wrong. Heavy and light fall together — *unless* the air gets in the way. Drop a cannonball and a feather and of course the feather loses. But that is the *air*, not the weight. Remove the air and they land together.

BORRO And how, precisely, do you propose to remove the air?

GALILEO *(a pause)* I can't.

BORRO *(triumphant)* Ah!

GALILEO Not yet. Somebody will. *(to the audience)* In 1971 a man dropped a hammer and a feather on the Moon, where there is no air. They landed together. It took three hundred and eighty years and a rocket, but I was *right*.

BORRO	What was that?
GALILEO	Nothing. <i>(SISTER CLARA enters.)</i>
CLARA	Signor Galilei. A word about the cathedral.
GALILEO	The cathedral is beautiful.
CLARA	You sit in it for two hours at a time with your fingers on your wrist, watching the lamp swing, and your lips moving. The verger thinks you are possessed.
GALILEO	I'm timing it.
CLARA	Timing the <i>lamp</i> .
GALILEO	With my pulse. I have no clock good enough. Sister — when the draught is strong, the lamp swings in a great wide arc. When it dies down, the lamp swings in a tiny little arc. And the time for one swing is <i>the same</i> . Wide swing or narrow swing, the same number of pulse beats. Always.
CLARA	<i>(despite herself)</i> ...Is it?
GALILEO	Every time. Which means a swinging weight could keep time. Better than any clock in Italy.
CLARA	<i>(a long pause)</i> So if the length of the chain decides the time, and not the size of the swing — then a shorter chain would swing faster.
GALILEO	<i>(delighted)</i> Yes! Exactly yes!
CLARA	And you could <i>choose</i> the time, by choosing the length.
GALILEO	Sister Clara, have you considered natural philosophy?
CLARA	I have considered it. They do not let me do it. <i>(to the audience, flatly)</i> So I keep the cathedral, and I watch the lamp, and I work it out on my own.
BORRO	This is all very charming, but none of it is in Aristotle.
GALILEO	No, Professor. It is in the <i>lamp</i> . Go and look at the lamp.
VINCENZO	<i>(to the audience)</i> He went. Years later. He never admitted it, but he went.

Discuss

1. Explain Galileo's string argument in your own words. Why is it so powerful?
2. He could not remove the air. Did that make him wrong?
3. "Go and look at the lamp." What does that tell you about how science should work?

Galileo really did use the tied-balls argument, and really did time a swinging cathedral lamp against his pulse. The famous Leaning Tower drop may never have happened. Dave Scott dropped a hammer and a feather on the Moon in 1971 — you can watch it. Borro was a real Aristotelian professor at Pisa; Vincenzo and Clara are invented.