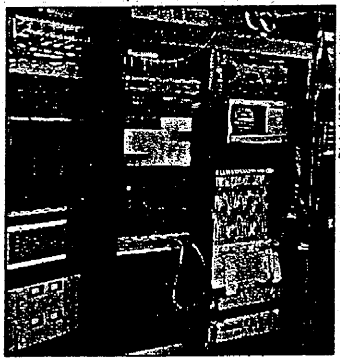
WHERE DID TV COME FROM?

THE SCIENTIST WHO ACCIDENTALLY INVENTED POP CULTURE

BY CARL SAGAN



Digital HDTV Grand Alliance

Below: Maxwell as a young man. Left: modern digital TV transmission electronics. Below right: The globe is the planet Venus. The large yellow-red feature is the Maxwell Mountain, discovered by radar astronomy.

SUPPOSE: YOU ARE, BY THE Grace of God, Victoria, Queen of the United Kingdom of Great Britain and Ireland and Defender of the Faith in the most prosperous and triumphant age of the British Empire. Your dominions stretch across the planet. Maps of the world are abundantly splashed with British pink. You preside over the world's leading technological power.

Suppose, around the year 1860, you have a visionary idea: You want a machine that will carry your voice, as well as moving pictures of the glory of the Empire, into every home in the kingdom. The sounds and pictures must come not through conduits or wires but, somehow, out of the air.

So, with the Prime Minister's support, you convene the Cabinet, the Imperial General Staff and the leading scientists and engineers of the Empire. You will allocate £1 million, you tell them (big money in 1860). If they need more, just ask. You don't care how they do it—just get it done.

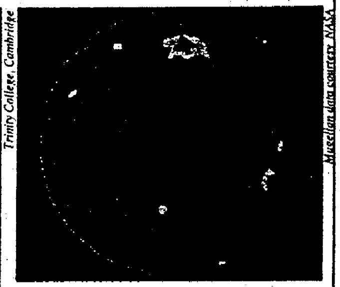
Probably there would be some useful inventions emerging out of such an endeavor—"spinoff." There always are when you spend huge amounts of money on technology. But the project would almost certainly fail. Why? Because the underlying science hadn't been done.

In the real world, the physics necessary to invent radio and television would come from a direction that no one could have predicted.

James Clerk Maxwell was born in Edinburgh, Scotland, in 1831. At age 2, he found that he could use a tin plate to bounce an image of the Sun off the furniture and make it dance against the walls. As his parents came running, he cried out, "It's the Sun! I got it with the tin plate!" In his boyhood, he was fascinated by bugs, grubs, rocks, flowers, lenses, machines. It was humiliating, his Aunt Jane later recalled, "to be asked by a child like that so many questions one couldn't answer."

OFTEN, THE TECHNOLOGY THAT MAKES OUR CIVILIZATION COMES FROM BASIC 'IMPRACTICAL' RESEARCH

Trinity College, Cambridge



Magellan data courtesy NASA

Naturally, by the time he got to school, he was called "Dafty," *daft* being a Britishism for not quite right in the head. He was an exceptionally handsome young man, but he dressed carelessly—for comfort rather than style—and his Scottish provincialisms in speech and conduct were a cause for derision, especially by the time he reached college. And he had peculiar interests.

He made enormous contributions to astronomy and physics, but his greatest contribution was his discovery that electricity and magnetism join together to become light. The now-conventional understanding of the electromagnetic spectrum, running in wavelengths from gamma rays to X-rays to ultraviolet light to visible light to infrared light to radio waves, is due to Maxwell. So are radio, television and radar.

But Maxwell wasn't after any of this. He was interested in how electricity makes magnetism, and vice versa. I want to describe what Maxwell did, but his historic accomplishment is highly mathematical. Here, I can at best give you only the briefest and simplest flavor.

The Danish physicist Hans Christian Oersted had performed a little experiment in which electricity was made to flow down a wire and induce a nearby compass needle to waver and tremble. The wire and the compass were not in physical contact.

The great English physicist Michael Faraday had done the complementary experiment: He made a magnetic force turn on and off, and thereby generated a current of electricity in a nearby wire. Time-varying electricity had somehow reached out and generated magnetism, and time-varying magnetism had somehow reached out and generated electricity. This was called "induction" and was deeply mysterious—close to magic.

Faraday proposed that the magnet had an invisible "field" of force that extended into surrounding space—stronger close to the magnet, weaker farther away. You could track the form of the field by placing tiny iron filings on a piece of paper and waving a magnet underneath.

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WHERE DID TV COME FROM?/*continued*

The electricity in a wire, we now know, is caused by submicroscopic electrical particles called electrons, which respond to an electric field and move. The wires are made of materials like copper, which have lots of free electrons—electrons not bound within atoms but instead able to move. Unlike copper, though, most materials, like wood, are *not* good conductors; rather, they are insulators. In them, comparatively few electrons are available to move in response to an electric or magnetic field. Not much of a current is produced.

Maxwell devised a way of writing down what was known about electricity and magnetism in his time—four equations summarizing precisely all those experiments with wires and currents and magnets.

The first of the four Maxwell equations tells how an electric field, due to electrical charges (electrons, for example), varies with distance. (It gets weaker the farther away we go.) But the more electrons in a given space, the stronger the field.

The second equation tells us that there's no comparable statement in magnetism. Saw a magnet in half, and you won't be holding an isolated "north" pole and an isolated "south" pole; each piece now has its own "north" and "south" poles.

The third equation tells us how a changing magnetic field induces an electric field.

The fourth describes the converse: how a changing electric field (or an electrical current) induces a magnetic field.

SUPPORT FOR BASIC SCIENTIFIC RESEARCH IS VITAL FOR THE FUTURE OF HUMANITY

The four equations are essentially distillations of generations of laboratory experiments.

Maxwell then asked himself a strange question: What would these equations look like in empty space, in a vacuum, in a place where there were no electrical charges and no electrical currents? We might very well anticipate no electric and no magnetic fields in a vacuum.

In the equations for empty space, the symmetry between the magnetic and electric fields should be preserved, Maxwell intuited. Even in a vacuum—in the total absence of electricity or even of matter—a changing magnetic field, he proposed, elicits an electric field, and vice versa. The equations were to represent Nature; and Nature is, Maxwell believed, beautiful and elegant. This partly esthetic judgment has done more to shape our civilization than any 10 recent Presidents and Prime Ministers.

When the equations were written down, Maxwell was readily able to show that electric and magnetic fields propagated through empty space as if they were *waves*. What's more, the velocity of the wave could be calculated. When Maxwell plugged in the numbers, he found that the electric and magnetic fields in a vacuum ought to propagate, astonishingly, *at the same speed as light*. The agreement was too close to be accidental.

Since light now appeared to behave as waves and to derive from electric and magnetic fields, Maxwell called them "electromagnetic." Those obscure experiments with batteries and wires had something to do with how we see, with what light is. Ruminating on Maxwell's discovery many years later, Albert Einstein wrote, "To few men in the world has such an experience been vouchsafed."

Living in a mechanical age, Maxwell felt obliged to offer some kind of mechanical model for the propagation of an electromagnetic wave through a perfect vacuum. So he imagined space filled with a mysterious substance he called the "aether," which supported and contained time-varying electric and magnetic fields much like a throbbing but invisible Jell-O permeating the Universe. The quivering of the aether was the reason that light traveled through it just as water waves propagate through water and sound waves through air.

The Bettmann Archive

Guglielmo Marconi used radio in 1901 to communicate across the Atlantic Ocean. Ironically, he is far better known than Maxwell. There has never been a TV program on the life of Maxwell, who made TV possible.

The whole idea of light and matter moving through the aether was to lead, 40 years later, to Einstein's Special Theory of Relativity, $E = mc^2$, and a great deal else. Relativity, and experiments leading up to it, showed conclusively that there is no aether supporting the propagation of electromagnetic waves. The wave goes by itself. The changing electric field generates a magnetic field; the changing magnetic field generates an electric field. They hold each other up by their bootstraps.

The linking up of the modern world economically, culturally and politically by broadcast towers, microwave relays and communication satellites traces directly to Maxwell. So does television; radar, which may have been the decisive element in the Battle of Britain and in the defeat of the Nazis in World War II; the control and navigation of airplanes, ships and spacecraft; radio astronomy and the search for extraterrestrial intelligence; and significant aspects of the electrical power and microelectronics industries.

If Queen Victoria had ever called an urgent meeting of her counselors and ordered them to invent the equivalent of radio and television, they would, I think, have gotten nowhere. Meanwhile, on his own, driven only by curiosity, "Dafty" was scribbling away.

Basic research is where scientists are free to pursue their curiosity and interrogate Nature, not with any short-term practical end in view but to seek knowledge for its own sake.

Maxwell wasn't thinking of radio, radar or television when he first scratched out the fundamental equations of electromagnetism; Newton wasn't dreaming of spaceflight or communications satellites when he first understood the motion of the Moon; Roentgen wasn't contemplating medical diagnosis when he investigated a penetrating radiation so mysterious he called it X-rays; Curie wasn't thinking of cancer therapy when she painstakingly extracted minute amounts of radium from tons of the mineral pitchblende; Fleming wasn't planning on saving the lives of millions with antibiotics when he noticed a circle free of bacteria around a growth of mold; Watson and Crick weren't imagining the cure of genetic diseases when they puzzled over the X-ray diffractometry of DNA; Rowland and Molina weren't planning to implicate CFCs in ozone-depletion when they began studying stratospheric photochemistry.

These discoveries and a multitude of others that grace and characterize our time—to some of which our very lives are beholden—were made ultimately by scientists given the opportunity to explore what, in their opinion and under the scrutiny of their peers, were basic questions in Nature.

Of course there are many pressing problems facing our nation and our species. But reducing basic scientific research is not the way to solve them. Scientists do not constitute a voting bloc. They have no effective lobby. However, much of their work is in everybody's interest. Backing off from fundamental research constitutes a failure of nerve, of imagination and of that vision thing that we still don't seem to have a handle on. ■

Carl Sagan, a Pulitzer Prize-winner, is a recipient of the Public Welfare Medal, the highest award of the National Academy of Sciences. The citation reads in part: "No one has ever succeeded in conveying the wonder, excitement and joy of science as widely as Carl Sagan, and few as well...His ability to capture the imagination of millions and to explain difficult concepts in understandable terms is a magnificent achievement."