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Science in the Age of Accelerators*†

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Private Science, Public Science

Accelerators have brought the particle physicist to work and live in three worlds: the private world of science, the public world of science, and the world of large accelerators. Our private world is our apparatus, our data, our theories, our colleagues, our journals, our meetings, and above all our understanding of elementary particles. There are more intimate areas in that private world, the childhood toys and dreams that led us

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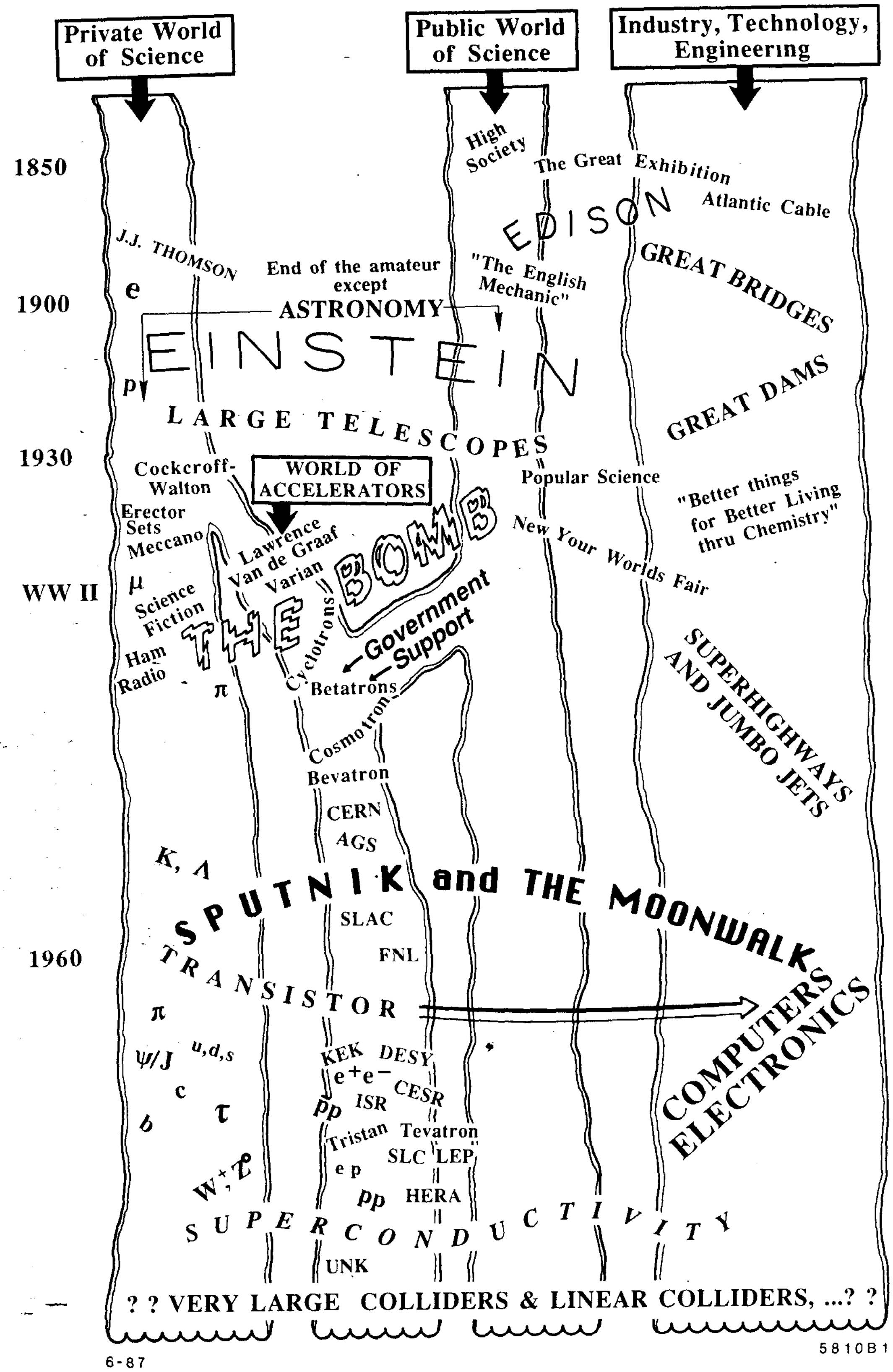
into physics. There is a connection between building huge accelerators and Erector sets and Meccanos and ham radios. There is a connection, sometimes a painful one, between childhood reading about lone science heros: Pasteur, Madame Curie, Einstein; and then growing up to be part of a group building or using a huge accelerator.

The public world of science is how society sees us, how we want to be seen in newspapers and on TV, how we interact with governments, and most important, how governments support science. Since the 1940's most of us in basic research have not been able to avoid the public world, even if we wanted to stay in our private world. Public money is needed to study agriculture as well as atoms, libidos as well as leptons. If the apparatus is table size, if the laboratory is room size, with a little obliqueness the dependence on public money can be ignored. The builders and users of large accelerators, of large telescopes, of space rockets and satellites cannot ignore their dependence.

At the Spring, 1987 Meeting[1] of the American Physical Society I used many slides and two screens to visually trace the intertwining of the private and public worlds of science with the coming of the age of particle accelerators. I was not trying to do the history or sociology or politics of accelerators. Rather I was illustrating some of the themes laid out historically in Fig. 1. (During my talk, Fig. 1 was always projected, here the reader will have to refer back to it).

There is not space here for all the pictures I used; I retain the unfamiliar images. The reader knows the familiar ones: Rutherford in the Cavendish Laboratory standing under a sign reading "TALK SOFTLY PLEASE"[2] or Livingston and Lawrence in front of the 37-inch cyclotron.[3] These and other familiar images I used came from Refs. 2, 3, and 4, of which the most entrancing is *The Particle Explosion* by Close, Marten and Sutton.[2]


Private World of Science
Public World of Science
Industry, Technology, Engineering
1850
1900
1930
WW II
1960
High Society
The Great Exhibition
Atlantic Cable
EDISON
J.J. THOMSON
e
End of the amateur except
ASTRONOMY
"The English Mechanic"
GREAT BRIDGES
EINSTEIN
p
LARGE TELESCOPES
GREAT DAMS
Cockcroff-Walton
WORLD OF ACCELERATORS
Popular Science
"Better things for Better Living thru Chemistry"
Erector Sets
Meccano
Lawrence
Van de Graaf
Varian
THE BOMB
New Your Worlds Fair
μ
Science Fiction
Ham Radio
Cyclotrons
Government Support
Betatrons
π
SUPERHIGHWAYS AND JUMBO JETS
Cosmotron
Bevatron
CERN
AGS
K, Λ
SPUTNIK and THE MOONWALK
SLAC
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TRANSISTOR
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π
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UNK
? ? VERY LARGE COLLIDERS & LINEAR COLLIDERS, ...? ?
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Before Accelerators

Before accelerators, J. J. Thomson's cathode ray tube apparatus (Fig. 2) was completely in the physicist's private world. The ideal apparatus, needing only a table and a glassblower, to identify the electron. Not so easy. Thomson writes, "It was only when the vacuum was a good one that the deflection [of the cathode rays] took place." Vacuum problems ninety years ago. In the same article Thomson asks " ...what are these particles? Are they atoms, or molecules, or matter in a still finer state of subdivision?"

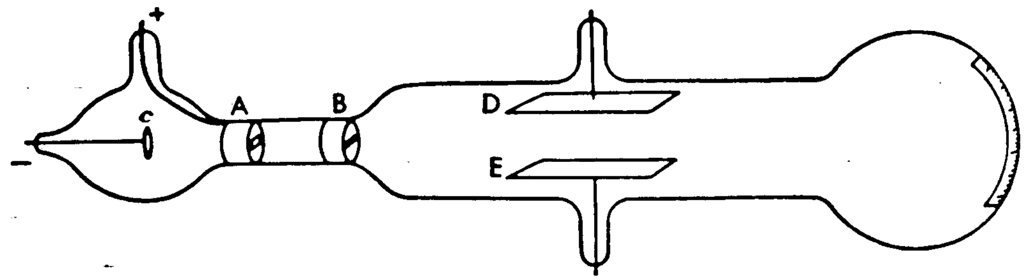


Fig. 2. From J. J. Thomson, Phil. Mag. **44**, 293 (1897).

Society with a capital S (High Society in Fig. 1) was interested in physics as culture and intellectual diversion. To the rest of society physics was hidden, remote. The submarine telegraphic cable (Fig. 3) is my

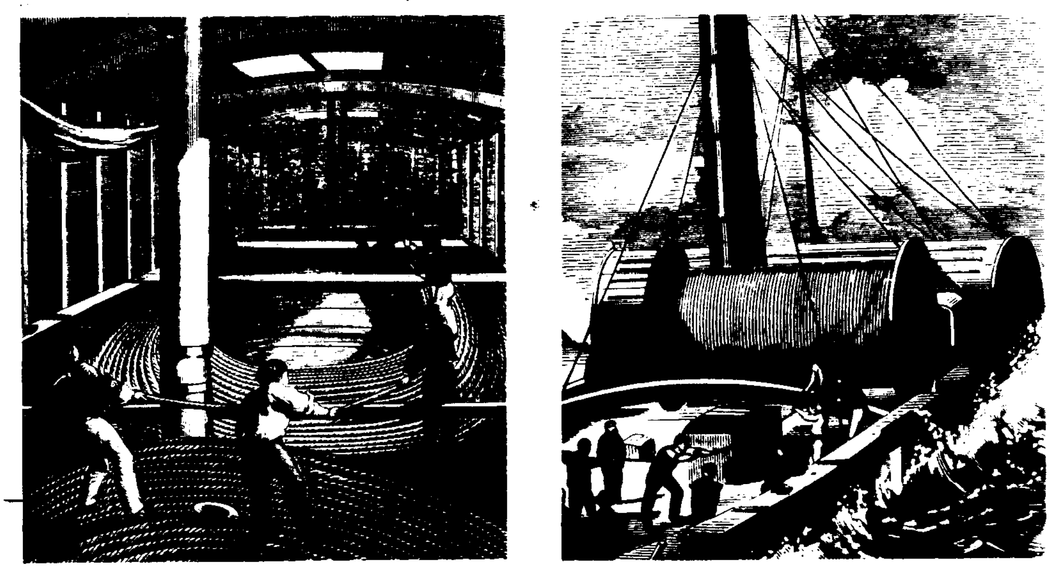


Fig. 3. Laying the Dover-to-Calais submarine cable in 1850.

metaphor. The public interest is in the enterprise and danger in laying the cable; it is in the wonder of connecting islands and continents. A great engineering feat. Hidden in all this is our physicist hero, Kelvin, and his theory of telegraphic signaling[5] and his idea of a stranded cable.

It is not pure science, but it is great engineering feats which catch the interest and enthusiasm of masses of people in the nineteenth and twentieth centuries: the Atlantic Cable, railroads, large steamships, great bridges (Figs. 4 and 5), great dams. Scientific apparatus can also be great engineering structures. First came the large telescopes, then space rockets and satellites, now huge particle colliders. I will return to this idea later because particle colliders as engineering feats can have special affection from the public and special support from governments. This brings benefits and dangers to particle physics.

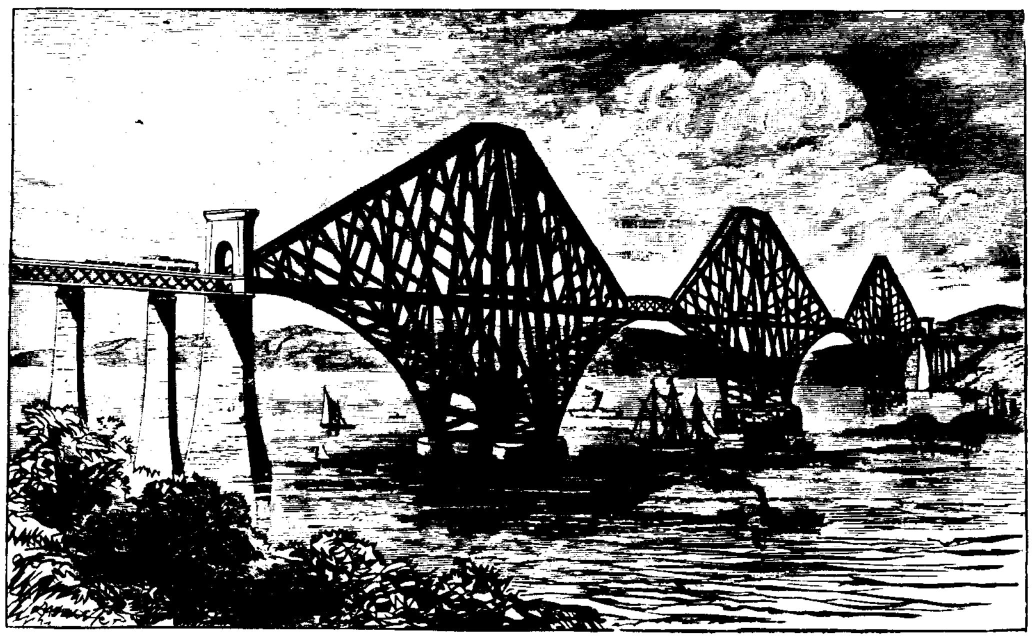


Fig. 4. The Forth Bridge, near Edinburgh, Scotland, completed in 1890. The first large bridge using the cantilever and central girder principle.

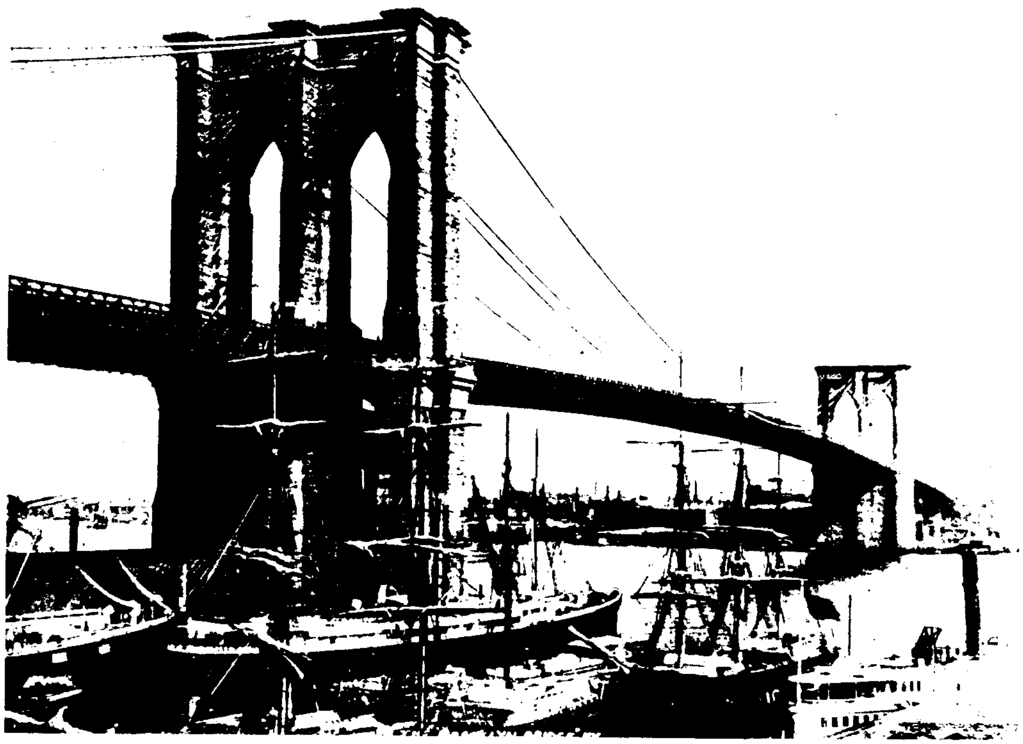


Fig. 5. The Brooklyn Bridge, New York, U.S.A., completed in 1883. One of the first large suspension bridges.

It is not pure science, but it is new and visible technology which catches the interest and enthusiasm of masses of people. From the Great Exhibition of 1851 — the Crystal Palace —in London (Fig. 6) to the Trylon and Perisphere of the 1939 New York Worlds Fair (Fig. 6), new and future technology has brought the crowds. The Great Exhibition was arranged in four departments: Raw Materials, Machinery, Manufacturers, and Fine Arts. Science is buried in technology.[6] Worlds Fairs fail these days because we are so immediately immersed in new technology.

In North America, Edison was and still is the great symbol of new and visible technology. During the reign of Edison, our private physics world moved on with Maxwell and Hertz and Lorentz and Planck, but Edison was a thousand times more famous. Only Einstein crossed the fame barrier out of our private world. His name stretched across the private and public worlds of physics (Fig. 1).

Fig. 6. Two Worlds Fairs: *Above*: The Great Exhibition of 1851 in London usually called the Crystal Palace. *Right*: The Trylon and Perisphere of the 1939 New York Worlds Fair. From a colored postcard.

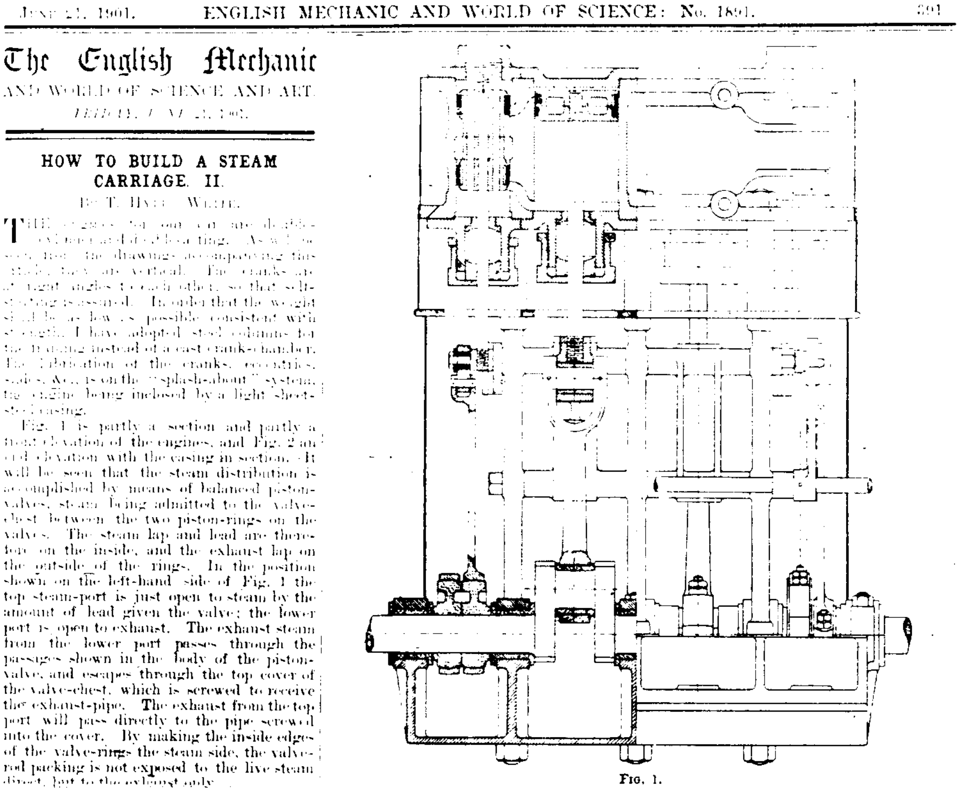
The End of the Amateur

In the last decades of the nineteenth century, a new gulf appeared between the private and public worlds of science. As sciences developed amateurs could no longer contribute or even fully understand. The usual example is the ninth edition of the Encyclopedia Britannica (1889), the last edition whose physics articles were useful to the professional and to the amateur. After that we have our Handbuch der Physik, and the encyclopedias stay with the public world.

An example I like is *The English Mechanic*, a combined do-it-yourself and amateur scientist magazine (Fig. 7). Building a steam car is an impressive hobby, but the inside contents of *The English Mechanic* are more impressive. In this issue there is a summary of a lecture by Dewar on liquid and solid hydrogen; a note on the Curie's work on induced radioactivity; the positions of two new variable stars are given; and there are dozens of queries from readers on subjects ranging from using ammonia for renovating felt hats to using the formula

$$\int_{0}^{2\pi} \int_{r=0}^{r=6} AB\,d\theta\, r\,dr$$

There are no amateur science magazines or amateurs like that today. Except in astronomy. That lucky science has its subject in full view, still has crucial contributions from amateurs, and has apparatus which are also engineering feats. A hundred years ago telescopes were already impressive structures (Fig. 8).



JUNE 21, 1901. ENGLISH MECHANIC AND WORLD OF SCIENCE: No. 1891. 391

The English Mechanic
AND WORLD OF SCIENCE AND ART.
FRIDAY, JUNE 21, 1901.

HOW TO BUILD A STEAM CARRIAGE. II.

By T. Hyler White.

THE engines for our car are [illegible] As will be seen from the drawings accompanying this article, they are vertical. The cranks are at right angles to each other, so that self-starting is assured. In order that the weight shall be as low as possible consistent with strength, I have adopted steel columns for the framing instead of a cast crank-chamber. The lubrication of the cranks, eccentrics, slides, &c., is on the "splash-about" system, the engine being inclosed by a light sheet-steel casing.

Fig. 1 is partly a section and partly a front elevation of the engines, and Fig. 2 an end elevation with the casing in section. It will be seen that the steam distribution is accomplished by means of balanced piston-valves, steam being admitted to the valve-chest between the two piston-rings on the valves. The steam lap and lead are therefore on the inside, and the exhaust lap on the outside of the rings. In the position shown on the left-hand side of Fig. 1 the top steam-port is just open to steam by the amount of lead given the valve; the lower port is open to exhaust. The exhaust steam from the lower port passes through the passages shown in the body of the piston-valve, and escapes through the top cover of the valve-chest, which is screwed to receive the exhaust-pipe. The exhaust from the top port will pass directly to the pipe screwed into the cover. By making the inside edges of the valve-rings the steam side, the valve-rod packing is not exposed to the live steam direct, but to the exhaust only.

FIG. 1.

Fig. 7.

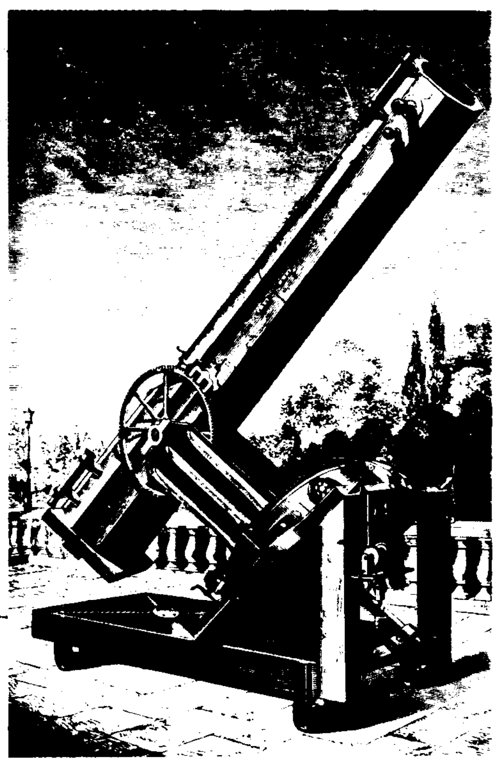


Fig. 8. *Left*: The 1864, 80 cm diameter, reflecting telescope of Foucault at Marseilles incorporating the innovations of a silver-on-glass surface and a parabolic figure. *Above*: The last of the great refracting telescopes, the 40 inch diameter at the Yerkes Observatory, installed in 1897.

The Thirties and Forties

The 1930's and 1940's represent the childhood of the age of accelerators in two ways. First, there are the early accelerators and their inventors: cyclotrons and betatrons and linear accelerators; Cockcroft and Walton and Lawrence and Van de Graff and Wideroe. Familiar names and images. Second, the thirties and forties were the childhood years of the physicists who have since dominated the building and use of large accelerators. That generation is retiring, or will soon retire, from the private world of science. What were our images of physics?

I think our images were quite different from the childhood images of physicists born after the Bomb or Sputnik or the Moonwalk. Before the bomb, physics was a very, very small and private world. In the thirties in the United States the most visible new technology and the public science was chemistry represented by the slogan of the Dupont Company — "Better Things for Better Living Through Chemistry". We, at least the accelerator builders and experimenters, came to physics mostly indirectly through Erector sets and Meccanos (Figs. 9 and 10) and ham radio. Our reading was the science and hobby magazines (Fig. 11) which were compounded of futuristic technology, science projects usually too complicated for our skill or pocket money (Fig. 12), and occasional perpetual motion (Fig. 13). Popular science magazines have degenerated since the nineteenth century, there was no perpetual motion in the *English Mechanic* because the editors knew the first law of thermodynamics.

We knew about a few physics greats: Kepler, Newton, Madame Curie if we went to the movies, and, of course, Einstein. But not Bohr or Schrodinger or Fermi or Michelson or Hahn and Strassman. These were great engineering projects going on in the thirties. Boulder Dam (Fig. 14), huge battleships, ocean liners, the China Clipper, and the Twentieth Century Limited entranced us. But we knew that wasn't science. Physics and chemistry and biology and astronomy were science; the problem was, "Could you make a living doing science?"

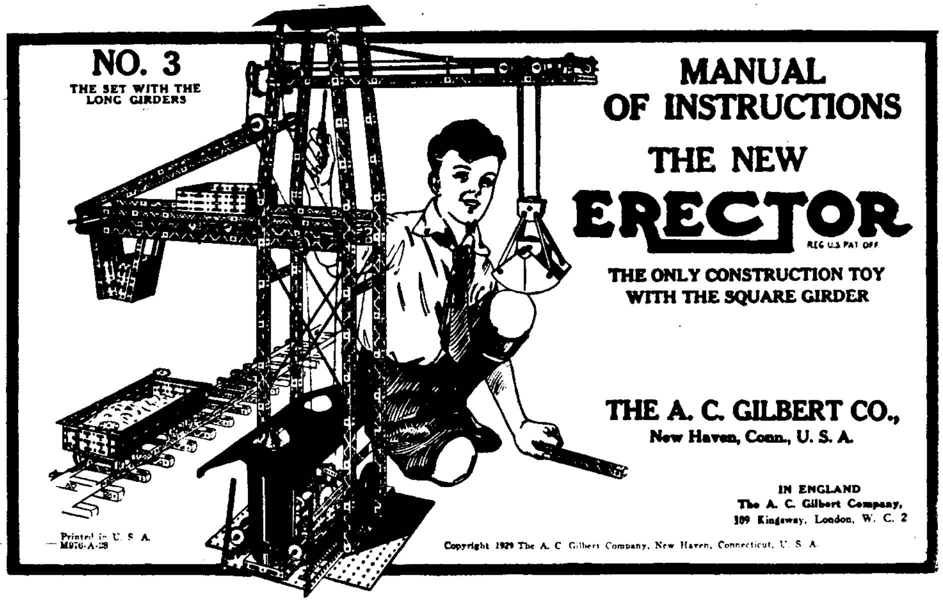


Fig. 9. Cover of 1929 Erector set manual.

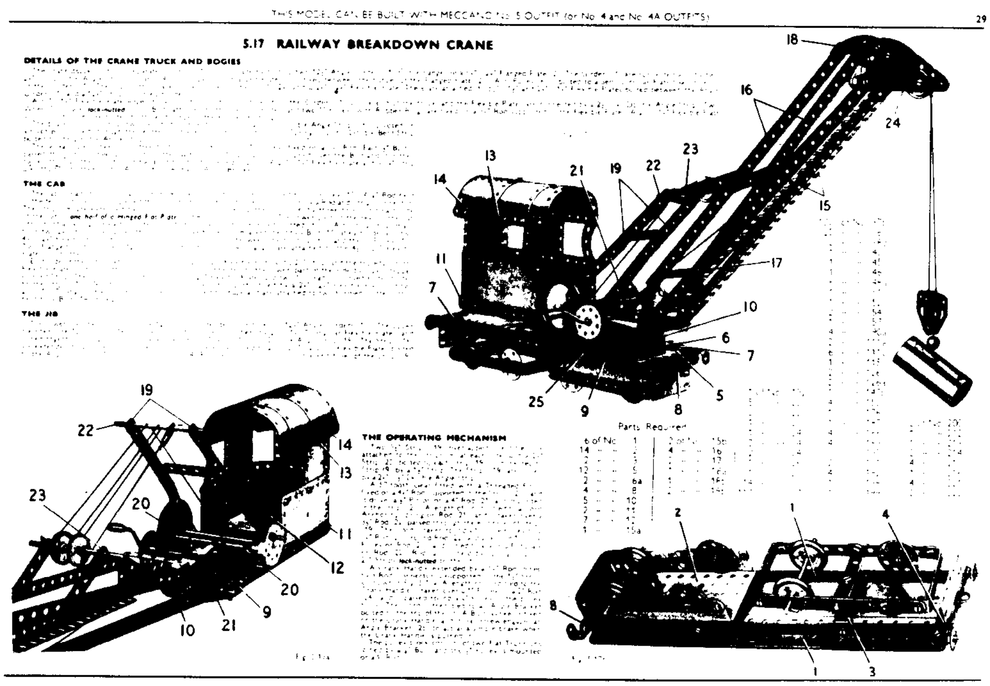
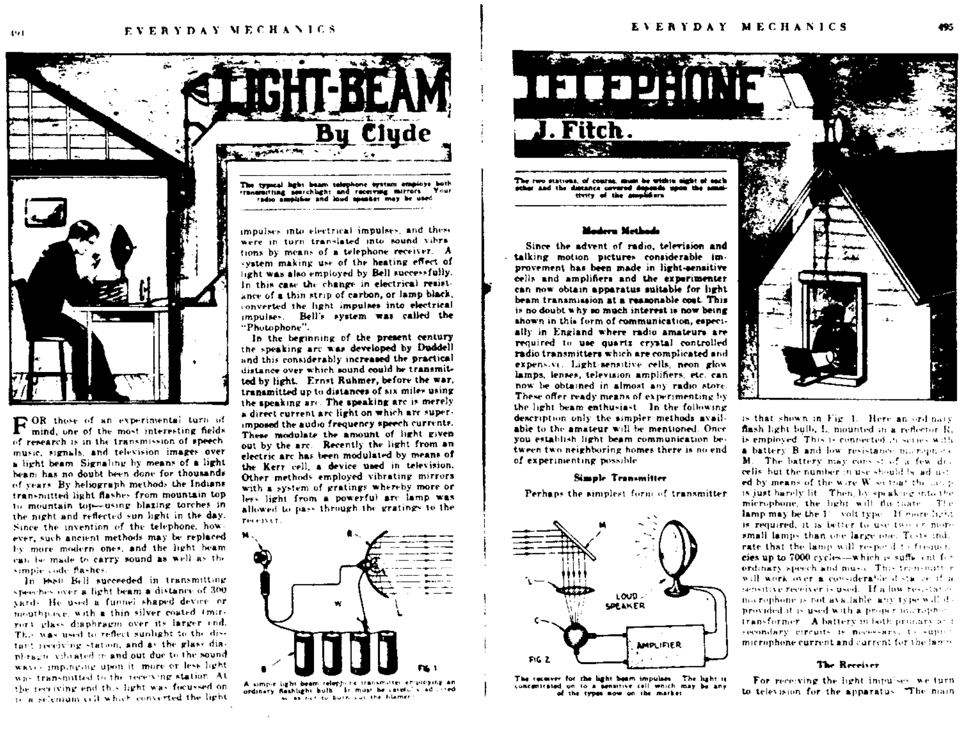


Fig. 10. Page of instructions from a 1930's Meccano manual.

Fig. 11. *Left:* Cover of December, 1930 Everyday Mechanics featuring the rotor force idea which was popular for futuristic ships and airplanes in the 1930's. The editor Gernsbach pioneered hobby electronics magazines and science fiction magazines in the 1920's. *Right*: Cover of February, 1934 Modern Mechanix.



494 EVERYDAY MECHANICS

EVERYDAY MECHANICS 495

LIGHT-BEAM TELEPHONE

By Clyde J. Fitch.

The typical light beam telephone system employs both transmitting searchlight and receiving mirrors. Your radio amplifier and loud speaker may be used

FOR those of an experimental turn of mind, one of the most interesting fields of research is in the transmission of speech music, signals, and television images over a light beam. Signaling by means of a light beam has no doubt been done for thousands of years. By heliograph methods the Indians transmitted light flashes from mountain top to mountain top—using blazing torches in the night and reflected sun light in the day. Since the invention of the telephone, however, such ancient methods may be replaced by more modern ones, and the light beam can be made to carry sound as well as the simple code flashes.

In [illegible] Bell succeeded in transmitting speeches over a light beam a distance of 300 yards. He used a funnel shaped device or mouthpiece, with a thin silver coated (mirror) glass diaphragm over its larger end. This was used to reflect sunlight to the distant receiving station, and as the glass diaphragm vibrated in and out due to the sound waves impinging upon it more or less light was transmitted to the receiving station. At the receiving end this light was focussed on to a selenium cell which converted the light impulses into electrical impulses, and these were in turn translated into sound vibrations by means of a telephone receiver. A system making use of the heating effect of light was also employed by Bell successfully. In this case the change in electrical resistance of a thin strip of carbon, or lamp black, converted the light impulses into electrical impulses. Bell's system was called the "Photophone".

In the beginning of the present century the speaking arc was developed by Duddell and this considerably increased the practical distance over which sound could be transmitted by light. Ernst Ruhmer, before the war, transmitted up to distances of six miles using the speaking arc. The speaking arc is merely a direct current arc light on which are superimposed the audio frequency speech currents. These modulate the amount of light given out by the arc. Recently the light from an electric arc has been modulated by means of the Kerr cell, a device used in television. Other methods employed vibrating mirrors with a system of gratings whereby more or less light from a powerful arc lamp was allowed to pass through the gratings to the receiver.

A simple light beam telephone transmitter employing an ordinary flashlight bulb. It must be carefully adjusted so as not to burn out the filament.

The two stations, of course, must be within sight of each other and the distance covered depends upon the sensitivity of the amplifiers.

Modern Methods

Since the advent of radio, television and talking motion pictures considerable improvement has been made in light-sensitive cells and amplifiers and the experimenter can now obtain apparatus suitable for light beam transmission at a reasonable cost. This is no doubt why so much interest is now being shown in this form of communication, especially in England where radio amateurs are required to use quartz crystal controlled radio transmitters which are complicated and expensive. Light-sensitive cells, neon glow lamps, lenses, television amplifiers, etc. can now be obtained in almost any radio store. These offer ready means of experimenting by the light beam enthusiast. In the following description only the simpler methods available to the amateur will be mentioned. Once you establish light beam communication between two neighboring homes there is no end of experimenting possible.

Simple Transmitter

Perhaps the simplest form of transmitter is that shown in Fig. 1. Here an ordinary flash light bulb, L, mounted in a reflector R, is employed. This is connected in series with a battery B and low resistance microphone M. The battery may consist of a few dry cells but the number in use should be adjusted by means of the wire W so that the lamp is just barely lit. Then, by speaking into the microphone, the light will fluctuate. The lamp may be the [illegible] volt type. If more light is required, it is better to use two or more small lamps than one large one. Tests indicate that the lamp will respond to frequencies up to 7000 cycles—which is sufficient for ordinary speech and music. This transmitter will work over a considerable distance if a sensitive receiver is used. If a low resistance microphone is not available any type will do provided it is used with a proper microphone transformer. A battery in both primary and secondary circuits is necessary to supply microphone current and current for the lamp.

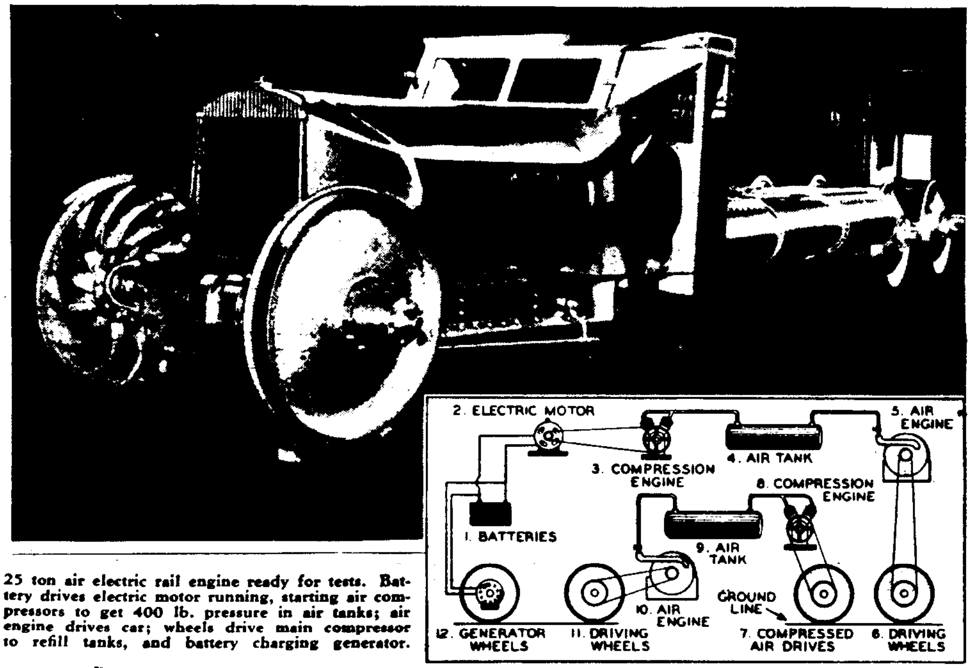
The receiver for the light beam impulses. The light is concentrated on to a sensitive cell which may be any of the types now on the market.

The Receiver

For receiving the light impulses we turn to television for the apparatus. The main

Fig. 12. A project from the December, 1930 issue of Everday Mechanics.

New Rail Car Runs on Air-Electric Perpetual Drive

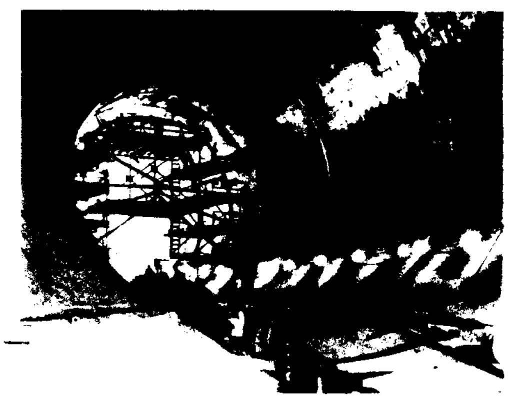


25 ton air electric rail engine ready for tests. Battery drives electric motor running, starting air compressors to get 400 lb. pressure in air tanks; air engine drives car; wheels drive main compressor to refill tanks, and battery charging generator.

FROM coast to coast by rail in 24 hours, traveling literally on air—that is what W. E. Boyette of Atlanta, Georgia, claims for his invention, a railroad engine that runs almost entirely on air.

Air for fuel—speeds of up to 125 miles an hour on rails—low transportation costs—these are possibilities conjured by Boyette's air electric car. After being started by batteries, the car needs only air to keep it running—a close approach to perpetual motion.

Fig. 13. A perpetual motion proposal from the February, 1934 issue of Modern Mechanix.



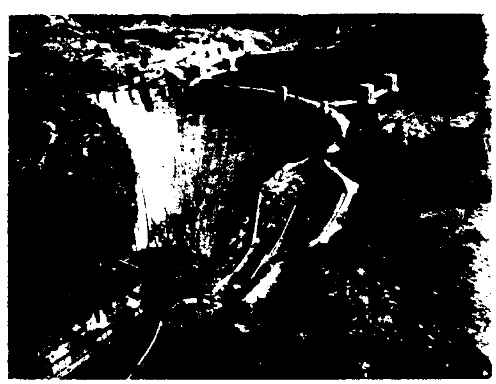


Fig. 14. *Right*: Boulder Dam across the Colorado River in the U.S.A. completed in 1935. *Left*: A tunnel used during the construction of Boulder Dam.

Physics Leaves Its Private World

After World War II the public discovered physics or rather discovered physicists. Not many physicists and not much physics, mostly it was the atom bomb and the hydrogen bomb and nuclear reactors and a little radar that caught the public. But this was enough for all of physics to cross the Rubicon into the public world of science: public interest, public scrutiny, public money.

There was only modest public interest or public scrutiny because we were still not associated with the new technologies and feats of engineering: superhighways, jumbo jets, Sputnik, and an astronaut walking on the moon. The newspapers and TV talked of rocket scientists but we knew they meant rocket engineers. Then the transistor appeared, and the newspapers and TV said that the transistor is physics. We had arrived.

The images are familiar now and I move quickly.

With the building of the Cosmotron and the Bevatron, with the construction of large alternating gradient synchrotrons, with the establishment of CERN, DESY, the Rutherford Laboratory, SLAC, (Fig. 15), Fermilab (Fig. 16), government support begins to flow steadily into the world of accelerators (Fig. 1). The builders and users of accelerators now live in three worlds.

We particle physicists are not alone in the necessity of living in three worlds. The same thing happens to space science, to plasma physics, and eventually to material science with its need for high intensity neutron and photon sources. Only the astronomers stay lucky — still able to get some of their telescopes from the world of private wealth. Although not the Hubble Space Telescope.

With public money, following the accelerator pioneers of the thirties and forties, following the dreams started with Erector sets and *Modern Mechanix*, we found there were two kinds of neutrinos (now three) and the proton was made of quarks. We found the ψ/J particles, the τ heavy lepton, the heavy b quark, the gluon that carries the strong force, and the $W^{\pm}$ and Z^0 that carry the weak force. It has been a splendid, an amazing, twenty-five years. I'm sorry that these discoveries have been given the awful and dull name "standard model". We have come so far in answering Thomson's question " ...or matter in a still finer form of subdivision?", our work deserves a better name.

Fig. 15. A view of SLAC showing the new Collider Hall for the SLC in the lower left corner. Photograph by Joe Faust.

Fig. 16. A view of Fermilab showing the experimental areas and Accelerator Complex, from the 1986 Annual Report of the Fermi National Accelerator Laboratory.

Large Particle Colliders:
New Physics, New Technology, Great Engineering Feats

As we plunged forward in our private world of quarks and leptons and intermediate bosons, our accelerator world moved closer and closer to the public world of science, and began to spill over into the industrial world (Fig. 1). In the past, connections between the accelerator world and the industrial world were fitful. We hungrily used some of their new technology — solid state electronics and computers. The passing from electron-positron storage rings to synchrotron light sources has begun to provide important applied research tools to industry. But mostly we kept to ourselves, except for the civil construction involved in building accelerators and accelerator laboratories: SLAC (Fig. 15), Fermilab (Fig. 16), and LEP (Fig. 17).

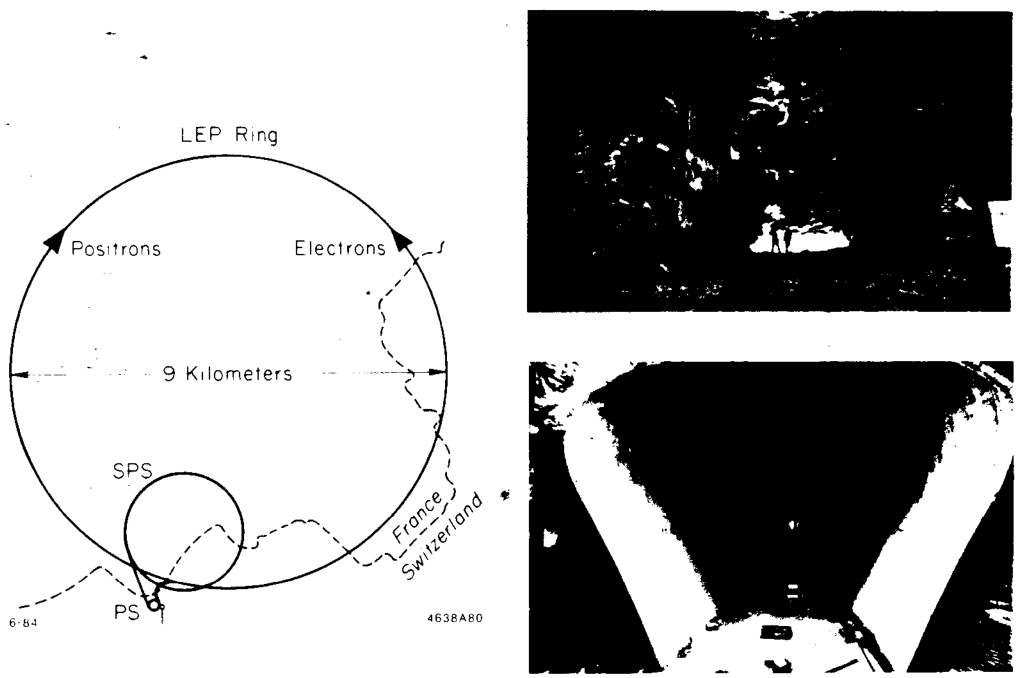


Fig. 17. *Left*: The LEP electron-positron collider under construction at CERN. *Upper Right*: The cave for the DELPHI experiment. *Lower Right*: The cave for the L3 experiment. It is interesting to observe the similarities between these photographic images and the Boulder Dam tunnel in Fig. 14. The photographs are from the CERN Courier, December 1986.

We can no longer keep to ourselves, as accelerators get bigger the civil construction to be done by the industrial world grows bigger. We might still build our own accelerator technical components, but we now have obligations to use industry for the sake of industrial development and for the sale of national economies.

We can no longer keep to ourselves. We need the spiritual and cultural and financial support of the public world of science. The public can provide that support because they continue to be interested and excited by great engineering feats, and that is what our accelerators have become. New and visible technology also interest the public. Our new technology is still esoteric: superconducting magnets (Fig. 18) and linear colliders (Figs. 19 and 20), but it is futuristic technology, and that is interesting to lots of people. There is also a fascination with the contrast between, on one side, the very small objects we study and the precision of some of our devices and, on the other side, the huge size of our tunnels and interaction regions and detectors.

As a demonstration my final two images (Fig. 21) are from a newspaper. Not the New York Times or the Washington Post, but the San Francisco Examiner[7] — a newspaper with an average mixture of national affairs, crime, local politics, and sports in its pages. The science reporter was given the space to do this article because the editors knew that large accelerators are news. Accelerators are news primarily because they are great engineering achievements, secondly because they incorporate highly visible new technology, thirdly, and this is a distant third, because we use them to learn more about the fundamental nature of matter. This is my thesis and my conclusion.

Fig. 18. A cross section of the superconducting magnet coil used in the Tevatron proton-antiproton collider. From the 1986 Annual Report of the Fermi National Accelerator Laboratory.

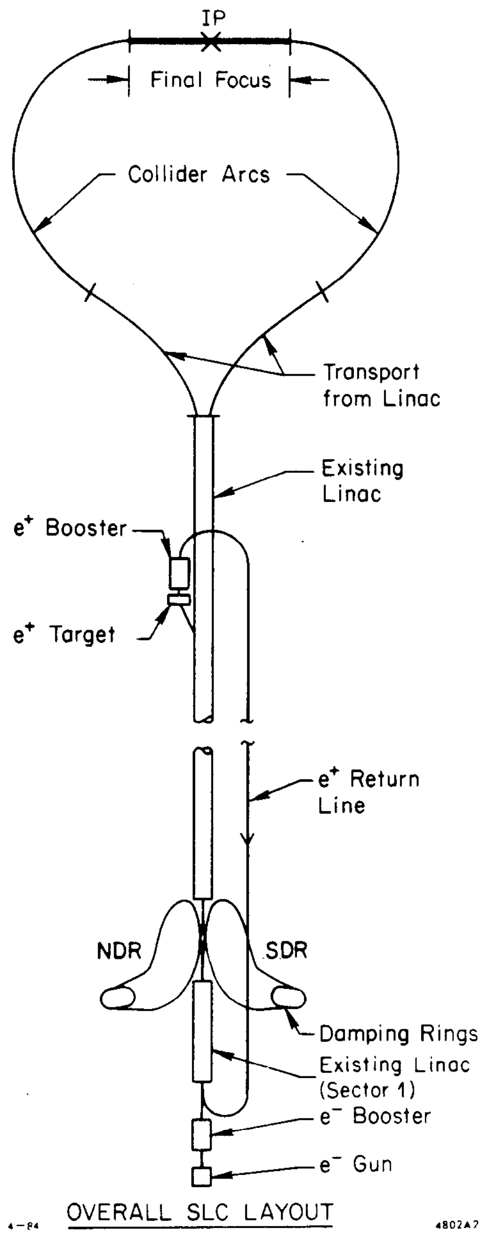


Fig. 19. Schematic of the principles of operation of the SLAC Linear Collider now being commissioned.

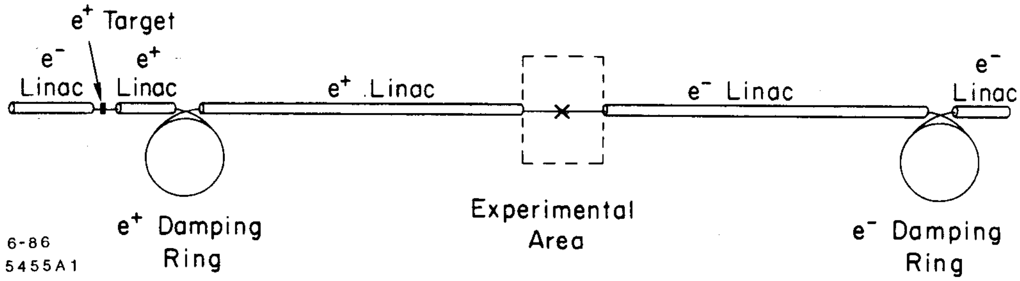
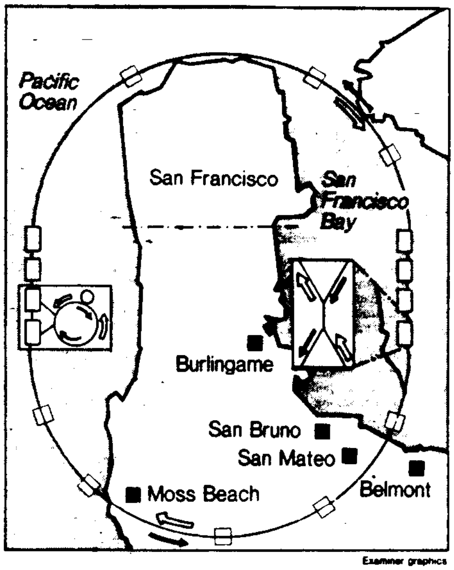
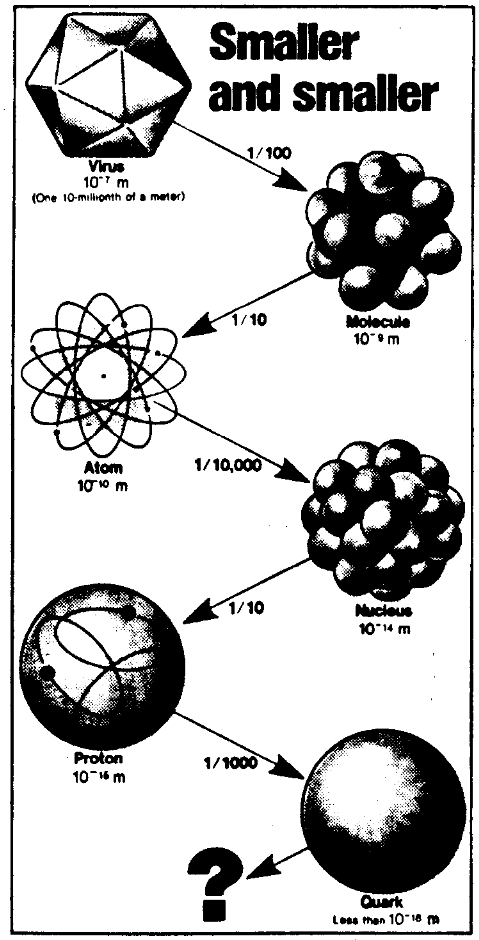


Fig. 20. Diagram for a future linear collider from J. Rees, SLAC-PUB-4037 (1986).



The Superconducting Super Collider won't be built in the Bay Area. But to visualize its size, imagine 52 miles of tube circling the northern tip of San Francisco, out into the Pacific, down below Moss Beach and San Mateo and over to the shores of Oakland. Price: more than $5 billion. It will work by launching two beams of protons in opposite directions at close to the speed of light. They will collide head-on in chambers, one enlarged at right, to create even smaller particles.



Stages in the structure of matter, from virus to quark. The characteristic sizes are given in meters. It is unknown if quarks have a measurable extent, with some internal structure, or if they are truly elementary, pointlike objects.

Fig. 21. Figures from articles in the San Francisco Examiner of April 19, 1987. The captions are from the articles.

I end with two warnings. The engineering images in this talk were of successful buildings and machines, there were no pictures of the Tacoma Narrows bridge, of the Challenger, of Chernobyl. If we are to build and use successfully the huge new accelerators, we must follow the principles of good engineering as well as good physics. We must know our technology well, we must design carefully — better we must overdesign, we must construct for strength and reliability and durability. If we can't get the public support to build our accelerators truly and well, we had better be honest with the public and tell them we can't do it. We must not fail with the huge accelerators we propose.

My second warning comes from the private world of science — in that dark country where we cannot know what is ahead in the physics of elementary particles. When Roebling designed the Brooklyn Bridge in the 1870's, he could promise that the bridge would take people from Brooklyn to Manhattan and back. It still does. We cannot promise that the next accelerator will take us to the Higgs particle or to the theory of everything or to the next heavy lepton, or even to the top quark.

It is difficult to avoid promises when science gets discussed and displayed in newspapers, on TV, and in government hearings, Witness the new high-temperature superconductors (Fig. 1). However if the promises of these superconductors are not kept, the public world will soon forget. There will be little harm to material sciences or solid state physics. If our huge accelerators fail, our promises will not be so easily forgotten.

Acknowledgements

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I apologize to my colleagues who are not from the United States or Great Britain for mostly using historical images from those two regions, those are the images I grew up with, feel closest to, and know best.

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