A Parable of the Pure and the Practical
Why We Must Pursue Basic Scientic Research

Talk presented at the Inauguration of theMesoamerican Centre for Theoretical Physics

Sheldon Lee Glashow

About the author

Harvard University, emeritus
Boston University

The Issue

Many representatives of Government, Industry and Academia argue that governments should invest only in research that is likely to generate immediate and specic benets, either wealth creation or improvements in the quality of life. They nd undirected research in particle physics, mathematics, cosmology, low-temperature physics and many other basic sciences to be useless and expensive luxuries that consume resources rather than promoting Economic Growth and Human Welfare. They are wrong!

Thesis (from a letter to the Economist)

Fundamental physicists would be hard-pressed to point to anythinguseful that was directly dependent on their theorising. The discoveries of particle physicists or cosmologists are intellectually irrelevant to almost everyone|does it matter how old the universeis or if matter consists of two or 17 particles? If individuals wish tocontemplate the universe, let them do it in their spare time at theirown expense. It is far more important that we encourage our \bestbrains" to solve real problems and leave theology to the religious professionals

Antithesis

Had Faraday, Rontgen and Hertz focussed on solving the \real problems" of their day, we would have waited much longer for electric motors, X-rays and radios. It is true that today's \fundamental physicists" are concerned with exotic phenomena that are not at all useful in themselves. Nonetheless, their work has made and continues to make an enormous impact on our lives. We shall demonstrate how curiousity-driven searches for fundamental knowledge have proven to be at least as eective as direct searches for solutions to specic societal problems, whether from the discoveries themselves or from the frontier technologies they required.

But our Critic has a point. Consider CERN:

World premiere research facility for high-energy physics; Supported by its 20 European member states; With 2500 full-time employees CERN hosts about 10,000 visiting scientists from 113 dierent countries.

CERN, among its accomplishments:

- Found the neutral currents of the electroweak theory,
- Used neutrinos to conrm the quark hypothesis,
- Discovered the W and Z bosons.
- Counted the number of neutrino species,
- Created the rst anti-atoms and
- Discovered the long sought Higgs Boson last year!

None of these triumphs are likely to contribute anything at all to human health or wealth. Useless Science?

Not quite useless: Think Technology Transfer!

CERN is a hotbed of innovative technologies involving Accelerators, Cryogenics, Detectors, Electronics, Information Technology, Magnets, Material Science, Superconductors &c. Through licencing or joint ventures, CERN makes these resources available for scientic and commercial purposes. Some examples of CERN's Technogical Spino:

- 1965 The World-Wide-Web, by physicists but for the world!
- 2004 GEANT-4: CERN's simulation software for physics, space science, edicine and radiology.
- 2003 DxRay, a spino company, develops advanced digital X-ray scanners based on CERN technology.
- 2012 \Thanks to scientists working on particle acceleration at CERN, the Geneva International Airport is the proud

owner of the largest solar energy system in Switzerland" (Forbes).

But CERN's primary purposes are to pursue the secrets of Nature and to train the next generation of innovators.

The Many Virtues of Basic Science: I. Clinical Medicine

1894 X-Rays	CAT Scanners
1932 Antimatter	PET Scanners
1950 Nuclear Magnetism	MRI Scanners
1912 Radioactive Isotopes	Brachytherapy
1934 Cyclotron	Particle Beam Therapy
1957 Lasers	Microsurgery
1986 PCR	Forensic Medicine
1928 Penicillin (by Chance!)	Disease Control
1953 DNA Structure	Gene Therapy

Each of these discoveries earned a Nobel Prize!

II. Basic Science and Information Technology

1888 Radio Waves	Wireless Transmission
I947 Holography	Secure Credit Cards

1947 Transistors	1st Computer Revolution
1951 Integrated Circuits	2nd Computer Revolution
1966 Optical Fibers	Rapid Data Transmission
1976 PK Cryptography	Secure Data Transmission
1988 Giant Magnetoresistance	Disk Readout
1986 High T Superconductors	Energy Storage (?)
2012 Quantum Manipulation	Quantum Computers (?)

All but two of these discoveries earned Nobel Prizes!

III. Yet More Fruits of Basic Science

1839 Photovoltaic Eect	Solar Panels
1905 Photoelectric Eect	Charge Coupled Device
1912 X-Ray Diraction	DNA Structure
1916 General Relativity	Global Positioning
1938 Nuclear Fission	Nuclear Power
1949 Carbon Dating	Climate Research
1969 Charge Coupled Device	Digital Cameras
1985 Bucky-Balls (Fullerenes)	?
2004 Graphene	?

All but one of these discoveries earned Nobel Prizes!

How `Atom Smashers' Became Big Business

Cyclotrons were created for pure research: to study the basic building blocks of matter. But these and other particle accelerators contribute directly to wealth creation and human welfare. Some 30,000 accelerators operate today. Very few do fundamental research. Mostly they are used for industry and medicine: Ion Implantation, Material Processing, Particle Beam Therapy, Medical Isotope Production, Food Irradiation, Nondestructive Inspection etc.

Energy loss due to `synchrotron radiation,' once a problem at electron accelerators, has become a multi-billion dollar bounty. Synchrotron light is useful for many basic sciences, medicine and industry. About 70 of these large, expensive and sophisticated light sources are deployed in 20 countries. Far more powerful `Fourth Generation' light sources are on the horizon.

Between Idea and Implementation

GMR Eect to Gigabyte Hard Drives:	3 years
CCD to Digital Camera:	6 years
Transistor to Transistor Radio:	7 years
Radio Waves to Wireless Telegraphy:	11 years
Fission to Nuclear Power:	19 years
General Relativity to Global Positioning:	78 years
Photovoltaics to Solar Panels:	115 years

The latency period have can various causes, among them: Necessity (e.g., solar panels); War (e.g., nuclear power); or Missing Technology (e.g., GPS needs satellites and sophisticated electronics as well as general relativity.)

La Chance ne sourit qu'aux esprit bien prepare, Research must be done with eyes wide open

Five Very Short Stories

- Once upon a time a Prince searched for a needle in a haystack. Instead he found the farmer's daughter.
- In 1856 young Henry Perkin to tried to synthesize quinine. Instead, he discovered the rst aniline dye.
- In 1896 Henri Becquerel set out to prove that the sun emits X-rays. Instead, he discovered radioactivity.
- In 1965 a chemist was assessing the ecacy of an anti-ulcer medication. Instead he stumbled upon the blockbuster articial sweetener aspartame.
- In 1996, chemists at Pzer held clinical trials for a new drug to treat angina and hypertension. The trials failed, but an entirely unanticipated side eect on men led Pzer to market Viagra for male impotence.

International scientic cooperation a paradigm for peace among nations

Basic scientic research is among the few areas wherein nations of the world cooperate. Modern science emerged as an multinational endeavor: Copernicus (a Pole), Tycho Brahe (a Dane), Kepler (a German), Galileo (an Italian) and Newton (an Englishman) taught us our place in the heavens. Whilst these were all white, Christian, European men, today everyone can contribute to the Scientic Adventure regardless of nationality, religion, race or sex. Among many international collaborations:

- Alpha Magnetic Spectrometer: 16 nations
- International Space Station: 15 nations
- International Linear Collider: 19 nations

- ITER (Thermonuclear Research): EU + six nations
- CERN: Scientists from over 100 nations

States with Formal Contacts with CERN

Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Belarus. Belgium, Bolivia, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Ecuador, Egypt. Estonia, France, Finland, Georgia, Germany, Ghana, Greece, Hungary, Iceland, India, Iran, Ireland, Israel, Italy, Japan, Jordan, Korea, Latvia, Lebanon, Lithuania, Macedonia, Madagascar, Malaysia, Malta, Mexico, Montenegro, Mozambique, New Zealand, Netherlands, Norway, Pakistan, Palestine, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russia, Rwanda, Saudi Arabia, Singapore, Slovenia, Slovak Republic, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Thailand, Tunisia, Turkey, United Arab Emirates, United Kingdom, Ukraine, USA, Uzbekistan, Venezuela, Vietnam.

Five (of Many) Physicists Who Spun Themselves Off

- Allan Cormack: Nuclear and particle physicist, longtime chairman Tufts physics dept., invented the CAT scanner for which he won the Nobel Prize in Medicine.
- Walter Gilbert: Accomplished theoretical physicist became molecular biologist, shared Nobel in Chemistry, cofounder & rst CEO Biogen, now celebrated art photographer & philanthropist.
- Paul Ginsparg: Theoretical physicist and IT expert, founder of the free online archive for physics and many other sciences. Won MacArthur award for \changing how physics gets done."
- Leon Lederman: Experimental physicist, codiscovered second neutrino & fth quark, Nobelist, many STEM initiatives, e.g., creating the Illinois Math & Science Academy.

- Andrei Sakharov: Famed Soviet theoretical physicist. human rights champion and Nobel Laureate in Peace, led his government to sign nuclear test ban treaty.

Technology Impacts Basic Science!

- Steam engines were invented long before they could be understood, thus challenging physicists to develop the science of thermodynamics.

- The 19th century inventions of spark coils (by Ruhmkor), photography (by Daguerre) and mercury air pumps (by Geissler) made many turn-of-the-century discoveries possible: radio waves, X-rays, radioactivity, the electron, atomic number, cathode ray tubes....

- The antenna used by Penzias and Wilson to discover the cosmic microwave background was built by ATT for early satellite communication.

- Mysterious gamma-ray bursts were detected by US Air Force satellites looking for illicit Soviet nuclear tests.

- Supercomputers enable otherwise impossible calculations in both pure and applied science, e.g., the four color theorem.