

Federal support for the physical sciences

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The role of basic science in society

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- Time frames
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- Examples of long-term payoffs from the physical sciences
- The social contract

A brief discussion of sixty centuries of physics

- The physics of the fundamental interactions
- One specific area of inquiry: why do most elementary particles have mass?
- How the UIUC Department of Physics fits in, briefly

Closing observations



The role of basic science in society

The heart of the matter: the role of the physical sciences in society

The conceptual foundations of research in the physical sciences– we seek to understand:

1. The nature of space and time;
2. The characteristics of the forces governing the interactions of matter and energy;
3. The origins of the fundamental properties (electric charge, mass, etc.) of the elementary particles, and the reasons for the existence of matter and energy;
4. The rich behaviors of complex systems composed of large numbers of elementary building blocks.

The time scales between fundamental discoveries in the physical sciences and their commercial and social impacts are measured in decades. Investments with such long time horizons are appropriate for the federal government, but not for industries (which must work towards shorter-term profitability).

The practical applications of discoveries in the basic sciences are of enormous value. The resulting technology is a principal driver behind the profound improvements in quality of life and the length of the human lifespan during the last two centuries.

Intelligently managed government support for basic research in the physical sciences (and its later industrialization) is the bedrock of American strength. It is the reason our society has preserved its democratic traditions in a dangerous world and has succeeded in spreading them throughout Europe, much of Asia, and parts of Africa.



In more detail: time frames for applications of basic science...

This is very important, and U.S. industry has had a hard time getting it right without federal encouragement. How do we balance the mix of projects expected to yield success in the short-term with those that are more speculative, but might have enormous impact in the future?

Concerning short time horizons...

- Short time horizons are appropriate for projects using known technology that can be characterized by reliable estimates of time to completion, probability of success, and project cost;
- Investors often desire predictable levels of (acceptable) risk with income-generating returns on investment within a few years;
- Two-year election cycle requires legislators to provide constituents with tangible successes in order to campaign successfully for reelection.

Concerning long time horizons...

- Long time horizons are appropriate for promising, highly speculative projects whose duration, cost, and ultimate outcome (and utility) are difficult to predict;
- Downside risk (loss of entire investment) is not negligible;
- Upside benefit is unlimited: new technology can change everything (*e.g.* invention of the transistor). Often benefits cannot be predicted at start of research effort. The surprises are the real money-makers.

Maintaining a technological edge is crucial for national strength/health/survival.

Support for basic science and the process of industrialization of new knowledge is one of the most important long-range tasks of the federal government.

...and some of the byproducts of our knowledge.

From basic physical principles discovered by 1916 have come:

- early communications technology
- early computers (vacuum tubes!)
- motors and engines, motorized transport, aviation
- telegraph, radio, television, radar
- generation and transmission of power
- industrial manufacturing...

...and from basic physical principles discovered by 1950 have come:

- ALL modern electronic devices
- nearly all medical instrumentation
- information processing, networked computers, high-speed data transmission
- generation and transmission of power
- precision manufacturing
- efficient control systems and the capacity to automate most tasks
- exponential growth in computing power and network bandwidth...

We understand a great deal about the structure of matter and materials. Almost all of the U.S. GDP is a direct result of commercial application of basic physics from the 19th and 20th centuries.

Specific examples of long-term payoffs from the physical sciences

Quantum mechanics → first modern computer: 33 years

- 1928: The Dirac equation provides an accurate description of the relativistic quantum mechanics of electrons
- 1947: Bardeen, Brattain, and Shockley invent the transistor (whose operating principles are entirely quantum mechanical)
- 1958: Kilby (at Texas Instruments) invents the integrated circuit chip
- 1961: The U.S. Air Force commissions Texas Instruments to build the first solid-state computer (100 kHz clock speed)

First modern computer → commercial use of WWW: ~34 years

- 1961: Texas Instruments solid-state computer
- 1969: ARPANET created; links 4 host sites
- 1973: Internet is created: a network formed of networks
- 1974: TCP/IP is created: “standard” for internet data transmission
- 1984: 1000 host sites on the Internet
- 1989: WWW created at CERN, including definition of HTML
- 1993: Mosaic (first web browser, evolved into Netscape) created at the University of Illinois at NCSA (funded primarily by NSF and the State of Illinois)
- 1995: ~10 million WWW hosts
- 2002: ~150 million WWW hosts

More examples

X-rays → CAT scanners for medical imaging: 80 years

1895: Wilhelm Röntgen discovers X-rays

1975: Robert Ledley is granted patent #3,922,552– “Diagnostic X-Ray System CAT Scan”

Nuclear magnetic resonance → MRI scanners: 31 years

1946: Edward Purcell and Felix Bloch develop precision methods for studying NMR

1977: Raymond Damadian builds the first whole-body MRI scanner

Superconductivity → Superconducting power lines: 91 years

1911: Kamerlingh Onnes discovers superconductivity in lead

2002: Detroit Edison replaces ~8 tons of copper cable with ~250 lbs of superconducting wire to deliver power to 14,000 suburban customers

Etc. etc.

Something to note: federal support for Dept. of Energy programs returns tax dollars to many industrialized states (Illinois, for example).



Is it just altruism on the part of the scientists?

No. Why do we (physical scientists) do it?

- Because we find it really, really interesting. We move through alien landscapes of inhuman strangeness filled with fire and beauty and return with jewels.
- We teach physics to our students because something this lovely should be shared.

I work in High Energy Physics. I know less about other subfields of physics. It's always been the case that the more I learn about my colleagues' research in other fields, the more I understand why they are as absorbed by it as I am by my own.

The social contract... why is it reasonable for the US government to support basic research?

- The long-term benefits to society are of extraordinary value
- Government can act in the national interest by supporting industrialization of promising technologies.
- Government is able to support projects whose time frames are longer than those acceptable to profit-driven industry

Scientists understand this. We realize we are lucky to love doing something which others choose to support because of its future value.



My area of research:
the physics of the fundamental interactions

The physics of the fundamental interactions

Six thousand years of inquiry with three basic themes. We seek to understand:

1. the nature of space and time
2. the characteristics of the forces governing the interactions of matter and energy
3. the origins of the properties of the elementary particles and the reasons for their existence

We've figured out a lot about #1, #2, but much less about #3:

1. Nature works according to Einstein's theory of relativity: moving clocks tick more slowly; moving objects become smaller; light rays bend in gravitational fields. (1916)
2. Nature works according to the principles of quantum mechanics: it's not at all like a giant billiard table. The forces are mathematical generalizations of those associated with electric fields.
3. We have good (but untested) ideas about the origin of mass. We're fairly clueless about the origins of many other properties. This is where research is now focused.

The names we use:

1. Classical Electrodynamics (Maxwell) + Theory of Relativity (Einstein)
2. Relativistic Quantum Field Theory (Dirac, Feynman, Weinberg,...)
3. Supersymmetry? String theory? D-branes? M theory?

All modern technology has its origins in the physical principles elucidated by these theories.



One specific area of inquiry: why do most elementary particles have mass?

Some particles are massless, some are not.

- Massless example: light (photons). Photons carry energy but have no mass.
- Massive example: electrons. 500,000,000,000,000,000,000,000,000 e^- per lb.

Why aren't all elementary particles massless?

Actually, we think nearly all of them are massless. We think:

- Deep inside them there's no mass at all.
- Interactions with one part of the violent quantum sea of empty space changes their kinematic properties so that they act as if they had mass. (Compare sprinting through a crowded Metro station to running along an empty street)
- Interaction with the hypothetical “higgs field” allows massless electrons, quarks, etc. to behave (at subatomic distance scales and larger) as if they were massive.

Sounds bogus. But the theory works very well so something like the higgs field is in there.

- Theory + existing data: higgs particle probably weighs ~150 proton masses
- Try to produce them directly: at LHC (“large hadron collider”) in Geneva, and the proposed Linear Collider. This is the “Holy Grail” of High Energy Physics.
- **Northern Illinois** (at/near Fermilab) is an excellent site for the LC. **We would like this large international facility to be built in the United States.** Other suitable sites are in California, Germany and Japan. (OMB cap!?!?!?)



How the UIUC Department of Physics fits in, briefly

UIUC has a great physics department.

We play leading roles in a variety of international subfields of physics such as:

- High Energy (my field) and Nuclear Physics
- Condensed Matter Physics
- Cosmology and astrophysics

In a variety of rankings (*e.g.* *U.S. News*), the UIUC Physics Department is ranked higher than all other public universities' Physics Departments except U.C. Berkeley's.

Including those wealthy private schools (Caltech, M.I.T., Harvard, Princeton, ...) we're 9th.

We teach, we do research, we run cool outreach programs (Physics Van: 300 shows, 47,000 students during 8 years), we invent new educational methods and metrology.

The student:faculty ratio for undergraduate physics majors is 3.3:1. Our students have a small-school experience while attending a state university with 28,000 undergraduates.

Since 1994 we have completely rebuilt our introductory physics sequences. We teach nearly 5,000 undergraduates in these courses every year.

The intellectual and artistic vitality of the university is extraordinary and I can't believe how lucky I am to have landed a faculty position at UIUC.

Some closing observations

- Federal funding for basic research in the physical sciences has declined during the last 30 years.
- Domestic funding is not keeping pace with that of our colleagues and competitors working abroad.
- The long-term benefits from basic research in the physical sciences is enormous. Increased support will pay off handsomely.
- It is tempting to focus on short-term projects at the expense of long-term, more speculative efforts. This is unwise. The future consequences of short-sighted policy could be severe.
- The decision to double NSF funding over the next five years (signed into law at the end of 2002) is an excellent example of long-range planning by the federal government.
- A very large portion of physical science research is funded through the Office of Science. Representative Judy Biggert's bill (H.R. 34) proposes to increase its funding by approximately 60% over the next five years. H.R. 34 is a terrific initiative, and a natural companion to the increase in NSF funding. It is worthy of enthusiastic, bipartisan, bicameral support.

We share common interests. How may my colleagues and I be of help?