1. Is Technology Applied Science?

The linear model of innovation

Godin, B. (2006) 'The Linear Model of Innovation', *Science, Technology, & Human Values 31*, 639–67.

Basic research ⇒ Applied research ⇒ Development ⇒ Production and diffusion

Vannevar Bush
(1890-1974)

"Basic research... creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realism of science. Today it is truer than ever that basic research is the pacemaker of technological progress." *Science: The Endless Frontier* (1945, pg. 19).

1959: National Science Foundation's three components of research:

(i) *Basic or fundamental research*: Research projects that represent original investigation for the advancement of scientific knowledge and that do not have specific commercial objectives, although they may be in the fields of present or potential interest to the reporting company.

(ii) *Applied research*: Research projects that represent investigation directed to discovery of new scientific knowledge and that have specific commercial objectives with respect to either products or processes.

(iii) *Development*: Technical activity concerned with nonroutine problems that are encountered in translating research findings or other general scientific knowledge into products or processes.

- *Motivation*: Can now determine how funds have been allocated:
  - 9.1% of 1959 NSF research budget went to basic research.
  - 22.6% went to applied research
  - 68.3% went to development

- Taxonomies of innovation by economists and management school researchers:

Mees (1920)	Pure science, development, manufacturing
Schumpeter (1939)	Invention, innovation, imitation
Stevens (1941)	Fundamental research, applied research, bench research, pilot plant, production
Bichowsky (1942)	Research, engineering/development, factory/production
Furnas (1948)	Exploratory/fundamental research, applied research, development, production
Brozen (1951)	Research, engineering development, production, service
Maclaurin (1953)	Pure science, invention, innovation, finance, acceptance
Ruttan (1959)	Invention, innovation, technological change
Ames (1961)	Research, invention, development, innovation
Scherer (1965)	Invention, entrepreneurship, investment, development
Schmookler (1966)	Research, development, invention
Mansfield (1968)	Invention, diffusion, innovation
Myers and Marquis (1969)	Problem solving, solution, utilization, diffusion
Utterback (1974)	Generation of an idea, problem-solving or development, implementation, and diffusion

Sound familiar...?

Invention ⇒ Innovation ⇒ Entrepreneurship

"It is New York University Tandon School of Engineering's fundamental way of approaching academics and research by arming faculty and students with the tools and resources to turn their inspiration into applications, products, and services that take flight towards the market."

"It starts in the classroom…

To think like an inventor, you have to at times put down the text book and get your hands dirty. Project-based coursework confronts students with problems that don't have easy solutions, in fact, they often have many. By figuring out the best solution, students learn to push their thinking, refine their designs, and develop a taste for invention and innovation.

grows in the laboratory…

Some have called what's going on in the halls of the NYU School of Engineering a "research renaissance," a return to the spirited, rigorous scientific exploration that contributed to such life-altering advancements as the mass production of penicillin, the laser, and cell phone technology.

responds to real-world, 21st century needs…

Necessity is the mother of invention, and the needs of the 21st century are massive: cleaner ways to fuel our cars, homes, and cities; more efficient drugs to treat our sick; and safer ways to protect our online information, to name just a few. Invention, innovation, and entrepreneurship encourages faculty and students to apply their research to problems that may seem too big to fathom, but can no longer be ignored, and through hard work are ultimately, solvable.

and comes to life on the marketplace.

NYU School of Engineering has always been home to people who make things, but now we are also home to people who make businesses that make things."

- Is this just...

> "...a rhetorical tool used by scientists, management experts, and economists"? (Sismondo 2010, pg. 93.)

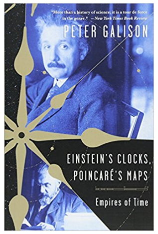
> "... a theoretical construction of industrialists, consultants, and business schools, seconded by economists"? (Godin 2006, pp. 640–1.)

- 17th-19th century distinction:
  - *pure research* = natural philosophy and abstract notions
  - *applied research* = mixed mathematics and concrete notions

- A rhetorical resource used for:
  - *defining, demarcating, and controlling professions to exclude amateurs.*
  - *financial support (by scientists)*
  - *raising the status of a discipline (by engineers)*
  - *attracting scientists (by industrialists)*

Claim 1. Technological practice is autonomous from science.

- Science is applied technology more than technology is applied science.
  - *tools, measuring instruments, recording instruments.*
- "Science owes more to the steam engine than the steam engine owes to science."
  - *Thermodynamics and the steam engine.*
  - *Special relativity and clock synchronization.*
  - *Computability and Turing machines.*



P. Galison (2003)
Einstein's Clocks, Poincare's Maps

- *Knowledge tradition* = body of knowledge tied to a particular group's social networks and material circumstances.

A paradigm is a package of ideas and methods which make up a view of the world and a way of doing science: "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity".

- For Kuhn, paradigms are *scientific* knowledge traditions. What about *technological* knowledge traditions?
- <u>*Claim*</u>: There are technological knowledge traditions that are independent of scientific knowledge traditions.

Claim 2. Science and technology are not sufficiently well-defined and distinct for there to be a relation between them.

- *Technological system* = electrical systems, manufacturing firms, utility companies, investment banks, etc.
  - *physical artefacts (transformers, transmission lines)*
  - *scientific artefacts (books, articles, research programs)*
  - *legislative artefacts (regulartory laws)*
  - *natural resources*

Hughes, T. (1987) 'The Evolution of Large Technological Systems.', in W. Bijker, T. Hughes, T. Pinch (eds.) *The Social Construction of Technological Systems*, MIT Press, 45–76.)

- Large technological systems blur boundaries between technology and science.

> "persons committed emotionally and intellectually to problem solving associated with system creation and development rarely take note of disciplinary boundaries, unless bureaucracy has taken command". (Hughes 1987)

- *Basic research is an ambiguous concept*: a rhetorical device that "draws on ideals of purity to gain funding and independence"

- Recall: *Technoscience* = causal interdependence of science and technology.
  - *biotechnology, nanotechnology, material science, etc.*

2. Does Technology Drive History?

***Technological determinism*:**
Material forces, and especially the properties of available technologies, determine social events.

- Emphasis on "real-word constraints" and "technical logics" that shape technological trajectories.
- Motivated from economics: material resources constrain social events.

Karl Marx
(1818-1883)

Ownership and control of the material means of production determines the modes of production and society.

***Technological essentialism*:**
Technologies have *essences* that
(a) determine how they are designed and produced,
(b) determine how they are used.

- Technological essentialism *entails* technological determinism.

***Technological anti-essentialism*:**

Technologies do not have intrinsic *essences*:

(a) Their design and production are socially determined.

(b) Their use is socially determined.

Claim 3: How a technology is used is not pre-determined.

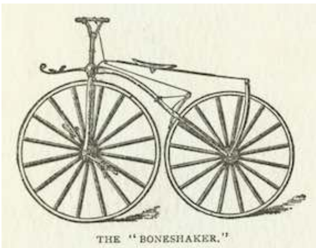
Example: No essence to a watch.

- *time recorder*
- *fashion statement*
- *profit generator*
- *status symbol*
- *email*
- *web-browser*
- *texting*
- *navigation*

Claim 4. How a technology is developed is not pre-determined.

- *Ex*: Development of the "safety" bicycle (1880s).
- Linear (pre-determined) model of development:

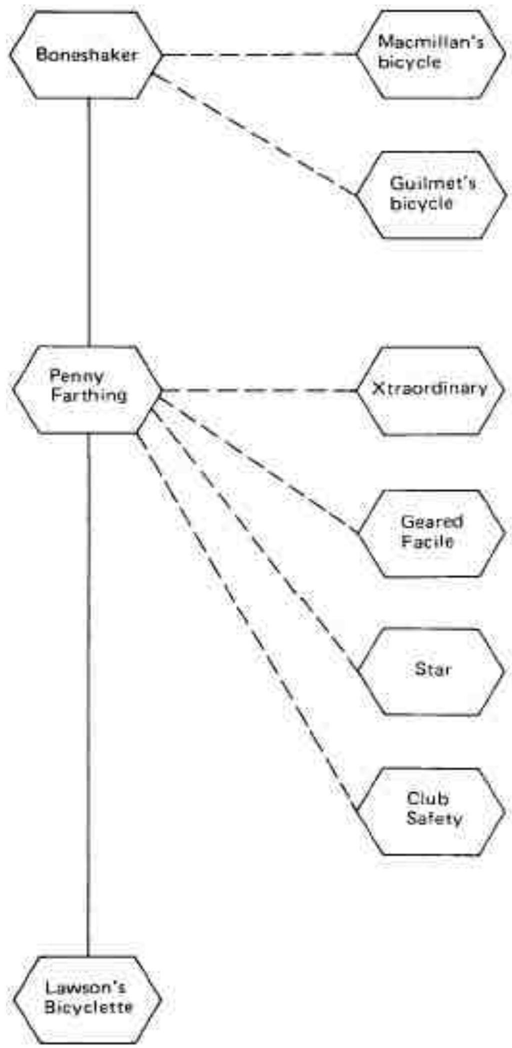
Pinch, T. & Bijker (1987) 'The Social Construction of Facts and Artifact...', in W. Bijker, T. Hughes, T. Pinch (eds.) *The Social Construction of Technological Systems*, MIT Press, 11–44.)



1860s


1870s

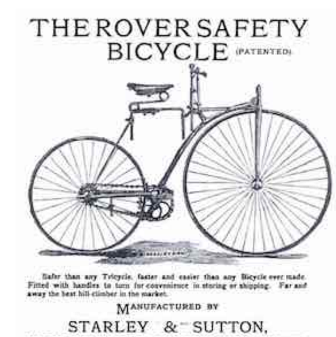
1879




Meyer et Guilmet 1869

1878


1879



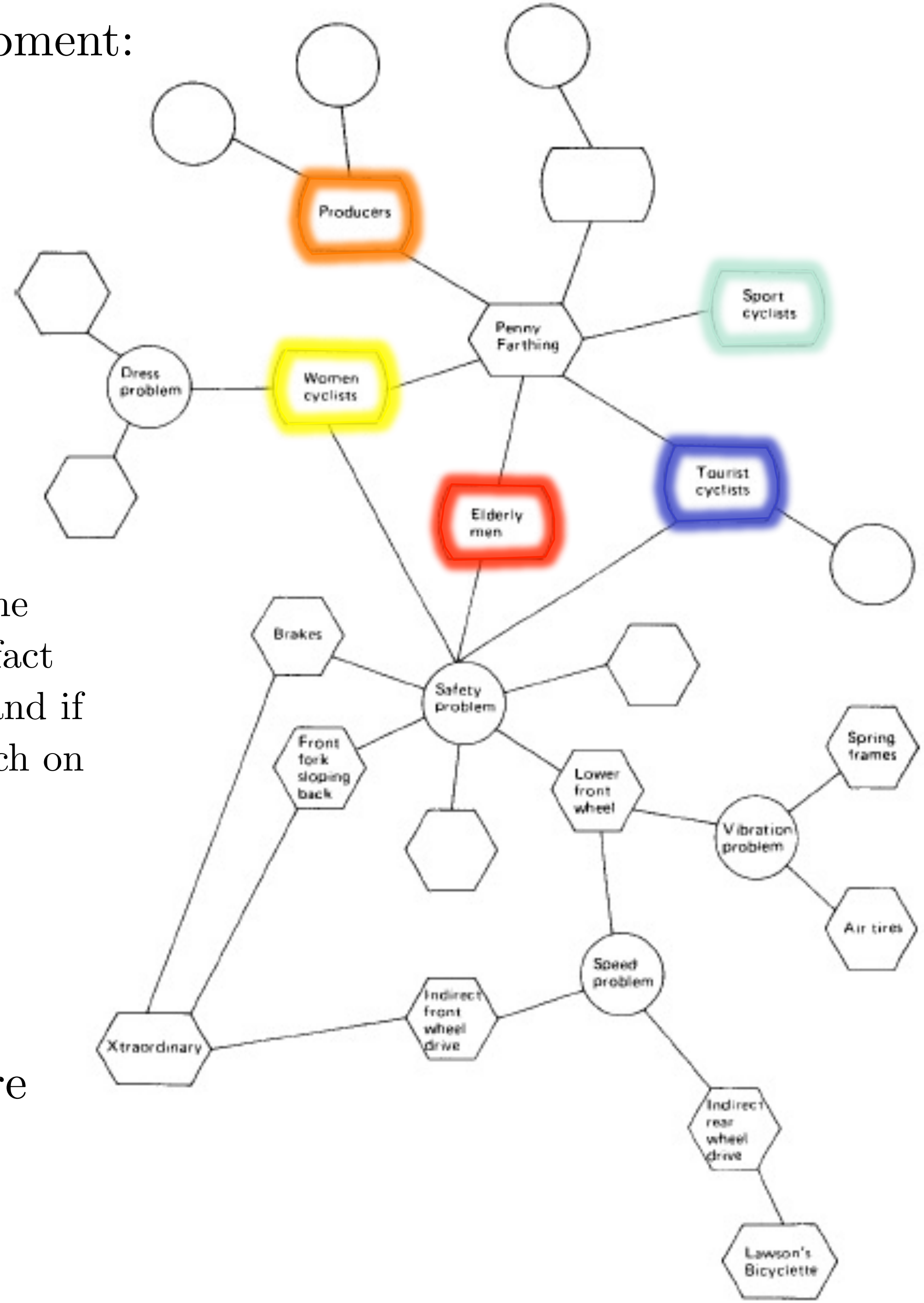
- Multi-directional model of development:

- Identify competing relevant social groups and problems:

  - *Sport cyclists.* "Young men of means and nerve: they might be professional men, clerks, schoolmasters or dons". Need for speed (daring Penny Farthing).

  - *Women cyclists.* Not supposed to ride the Ordinary (Penny Farthing): "The mere fact of riding a bicycle is not in itself sinful, and if it is the only means of reaching the church on a Sunday, it may be excusable." (1885)

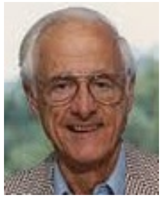
- _*Claim*_: "Safety" bicycle stabilized after 1898 into modern form, but not because its characteristics were essential and pre-determined.



- *Anti-essentialist Claim*: There is **interpretive flexibility** in the understanding of technologies:
  - *The way technologies are developed and evolve is the result of rhetorical operations that define the users, the uses, and the problems that particular designs solve.*
  - *The success of a technological artefact depends on the strength and size of the group that takes it up and promotes it.*
  - *Attention should be focused on users, not producers, of technology.*

- *Technological frame* = the set of practices and the material and social infrastructure built around an artefact.
  - *A frame guides future actions as it develops and reflects engineers' understandings of the key problems of the artefact.*
  - *A frame places constraints on interpretive flexibility.*

Vincenti, W. (1995) 'The Technical Shaping of Technology'



Walter Vincenti

Claim: The real world imposes intractable, non-negotiable constraints on what engineers can and cannot do.

- *"technical constraints" = real world constraints*
- *"technical logic" = technical + cost constraints; determines what designers/inventors can and cannot do.*

- *Example*: Development of Edison's electrical lighting system, 1877-82.
- *Goal*:

"...to effect *exact immitation* of all done by gas, so as to replace lighting by gas by lighting by electricity."

Thomas Edison
1847-1931

Strong Claim: Real-world constraints *completely determined* the design of Edison's electrical system.

Weaker Claim: Real-world constraints *influenced* the design of Edison's electrical system.

Technical constraints:

- Ohm's Law: $I = V/R$
- Joule's Law: $P = RI^2 = VI.$

> "...power engineers have to take them—in fact they think of them—
> as tantamount to the real world itself." (Vincenti 1995, pg. 556.)

> "Engineers can vary the values of the quantities in the equations, but they *cannot* alter the laws; in that, they have no choice." (Vincenti 1995, pg. 556.)

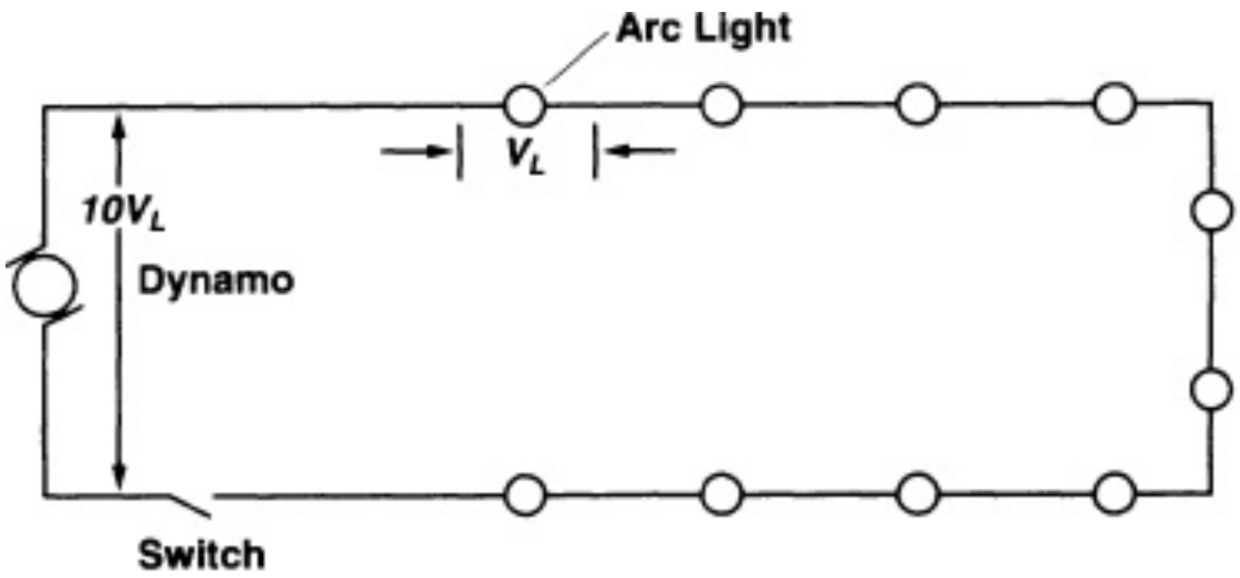
Some Initial Concerns:

- Equations are *not* the "real world itself". Equations relate properties (I, V, R, P) that we attribute to real physical phenomena (currents, conductors).

- Are equations the same thing as laws?
  - *Regularities?*
  - *Relations (necessary or contingent) between universals?*

- Are laws absolutely true, or merely approximative?
  - *To apply Ohm's and Joule's laws, engineers must make symplifying assumptions.*
  - *In real conductors, impurities may modify Ohm's law.*
  - *Errors in measuring instruments will entail that actually measured quantities will only approximate the laws.*

- *Option 1*: Low-resitance arc lights in a series circuit.



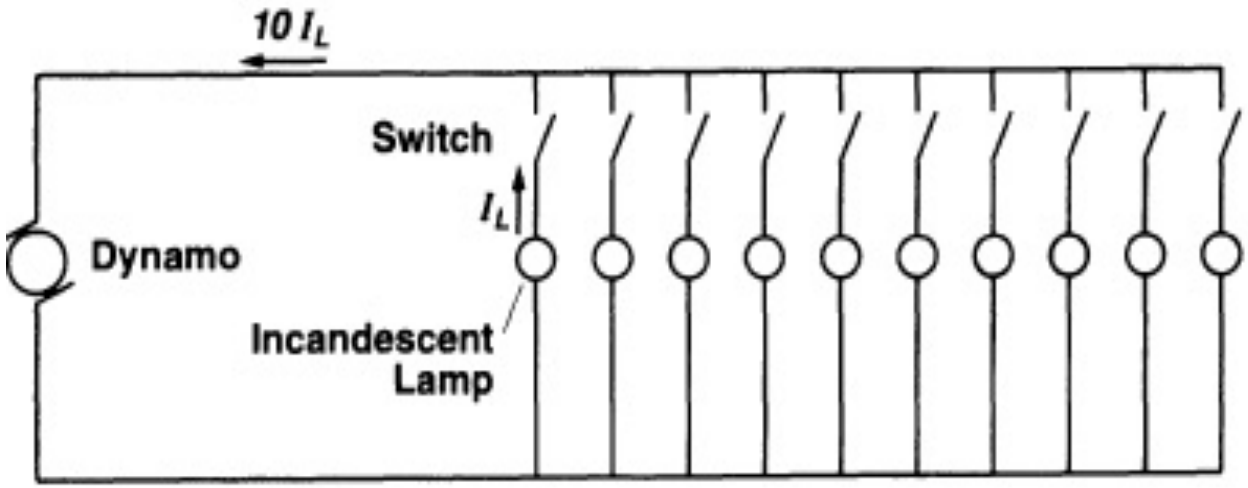
- *Switch turns all lights on or off together.*
- *Current is same through all lights.*
- *Sum of voltages across lights is equal to voltage supplied by dynamo.*

- Joules' law ($P = VI$) entails: For $500\,V$ limit of insulation, current must be high for a "feasible arc light".
- Ohm's law ($I = V/R$) entails: Resistance of each light must thus be low.
- *But*: "...for reasons of physical reality and overall cost, a low-resistance lamp of any kind was out of the question, and a high-resistance lamp was essential."

"Edison, aiming for home and office use and individual control, *was forced to a different path*." (Vincenti 1995, pg. 559.)

Why lamp resistance must be high:

- <u>*Option 2*</u>: High-resistance incandescent lamps in a parallel circuit.



- *Individual switch for each light.*
- *Voltage is same across all lights.*
- *Sum of currents through lights is equal to current supplied by dynamo.*

- For individual light control, need to put lights in a parallel circuit.
- For low-R arc lamps, I in transmission line must be high.
- <u>*Which means*</u>: To minimize power loss ($P = RI^2$), R in transmission line must be made small.
- <u>*But*</u>: Making R small for realistic transmission lines is too costly.
- <u>*Thus*</u>: Can't use low resistance arc lamps.

"There was only one escape from this dilemma." (Vincenti 1995, pg. 560.)

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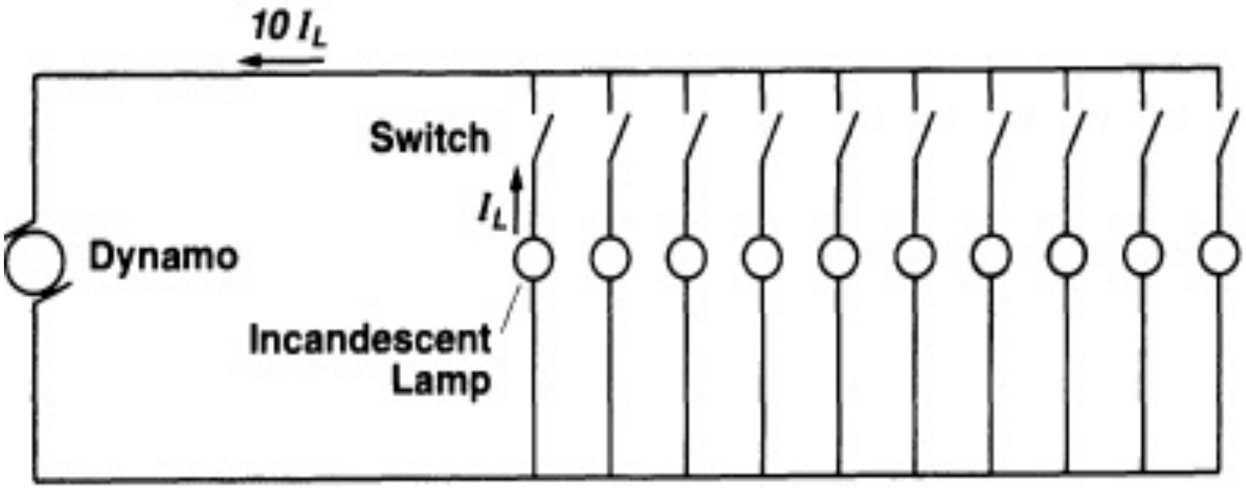

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- Joules' law ($P = VI$) entails that to maintain light output (P), can keep I low and make V high ("the converse of the arc-light situation").
- Ohm's law ($I = V/R$) then entails that for a given I, for high V, need a light with a high resistance.

"Given Edison's goal to imitate gas lighting, the real-world constraints of Joule's and Ohm's laws, plus cost, left no logical alternative." (Vincenti 1995, pg. 561.)

"Once Edison had made his decision, for whatever reasons, to imitate and compete commercially with gas lighting, with its individual control of lights and central-station distribution... his hands as a design engineer were, in important respects, tied." (Vincenti 1995, pg. 562.)

"All electrical engineers, if their devices are to work in the real world, have to adopt the concepts of resistance, voltage, current and power, plus the demands of Ohm's and Joule's laws, as absolute representations of [the physical] world." (Vincenti 1995, pg. 564.)

- Other examples of real-world constraints (according to Vincenti):

  (a) The impossibility of a perpetual motion machine.

  > "Though doubts had been voiced for some time, the possibility remained open theoretically until formulation of the first and second laws of thermodynamics in the mid-1800s."

  (b) "Gravity".

  > "This constraint requires that, to achieve flight, a lifting force must be provided... the existence of gravity has shaped a vast amount of aeronautical-engineering (and other) effort."

- *Note*: It's important to distinguish empirical phenomena and theoretical representations of empirical phenomena (Ohm's law, Joules' law, 1st & 2nd laws of thermodynamics, Newton's law of gravity).
- Theoretical representations are *never* absolute truths (recall the problems associated with confirmation); rather, they can be reliable in degrees.
- *Thus*: The constraints they place on design can never be absolute.

"Nothing I have said should suggest that I see any simple, literal technological determinism at work. The matter is one of real-world constraints and consequent logic, not impelling causes; 'room to maoeuvre' signifies just that." (Vincenti 1995, pg. 566.)

- *Strong Claim?* Real-world constraints *completely determined* the design of Edison's electrical lighting system.
- *Weaker Claim?* Real-world constraints *influenced* the design of Edison's electrical lighting system.