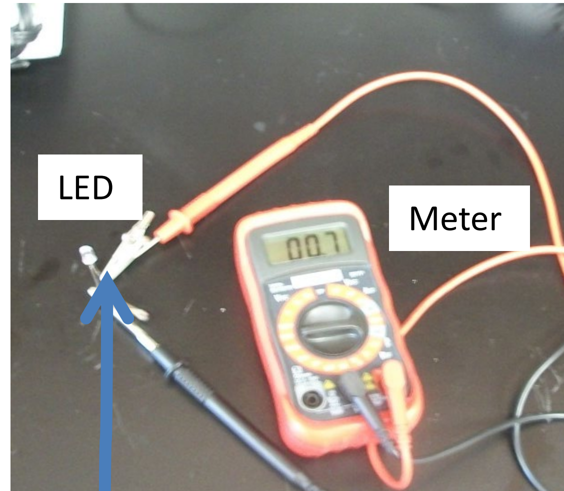
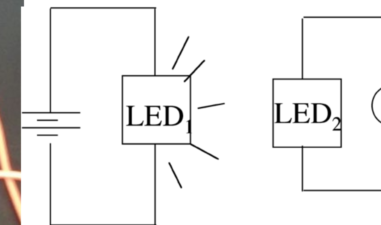
Light Emitting Diodes
Supplementary Background Materials

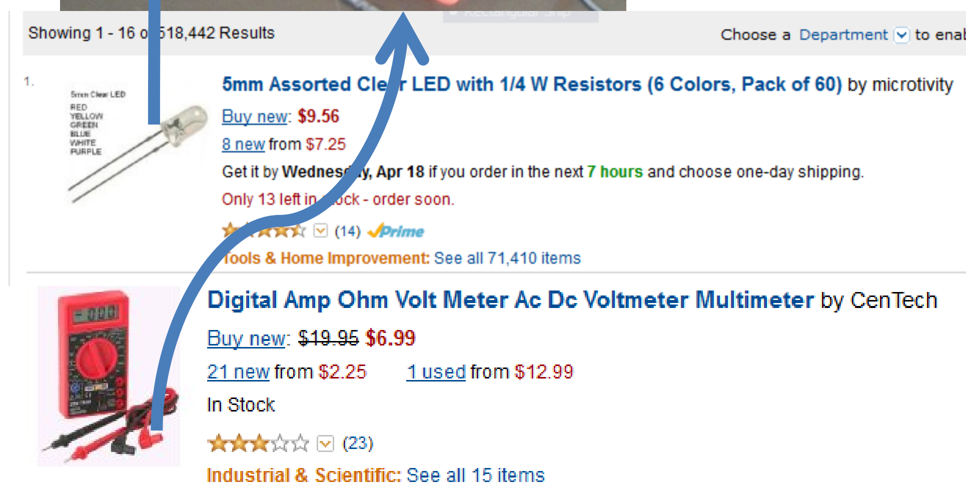
Version 052820

Interesting Properties of LEDs

- Usually LEDs are thought of as light sources
- LEDs are also light detectors
- We use this property to investigate the band gap structure of LEDs
- Use inexpensive LEDs and digital meter
- Available online for low cost







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Background

- Identify LEDs as an example of nano-scale structures
  - Three challenges in designing LEDs
    - Efficiently producing light
    - Efficiently extracting light
    - Wide range of colors

Thin film (nano-scale) deposition techniques

Selection of semiconductor materials/dopants

- Explain how quantum behavior of light and matter interact
  - Band gaps
  - Photons

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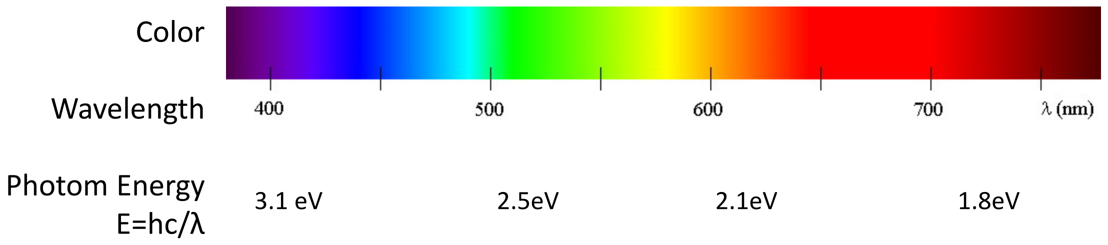
Light is composed of photons which have characteristic wavelengths that depend on their energy. For wavelengths between 400 and 800 nanometers, photons produce visible light.



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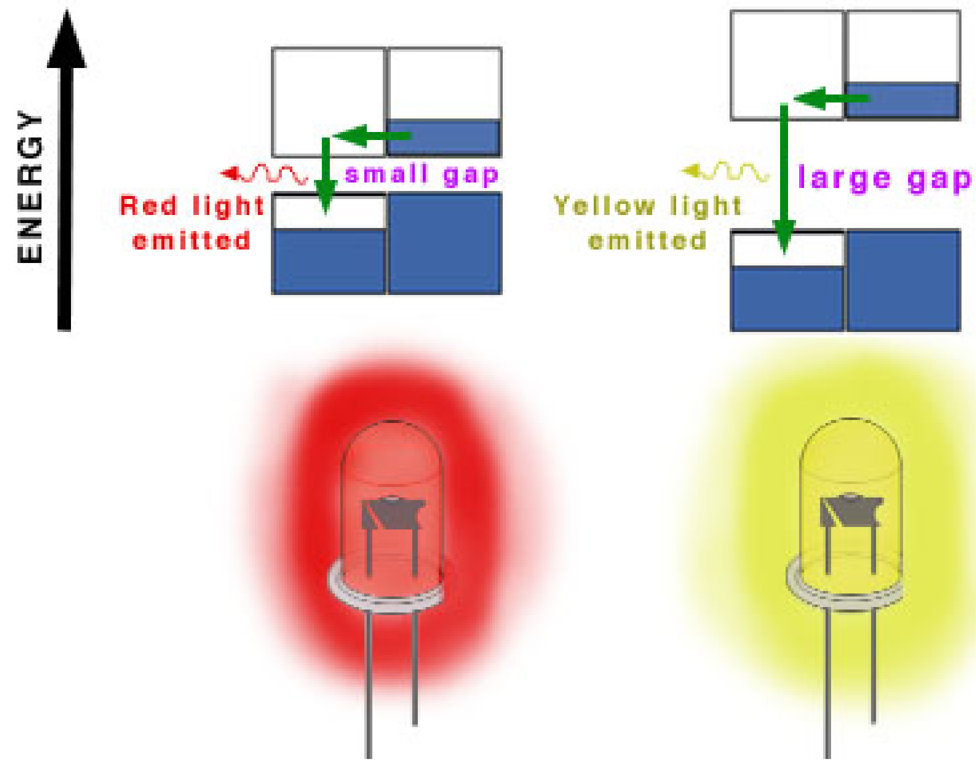
LED's are designed so that when electrical energy is applied, photons are emitted. The color of the light depends on the energy of the light, which is in turn controlled by the band gap designed into the LED Structure



http://www.chemistry.wustl.edu/~edudev/LabTutorials/PeriodicProperties/MetalBonding/MetalBonding.html

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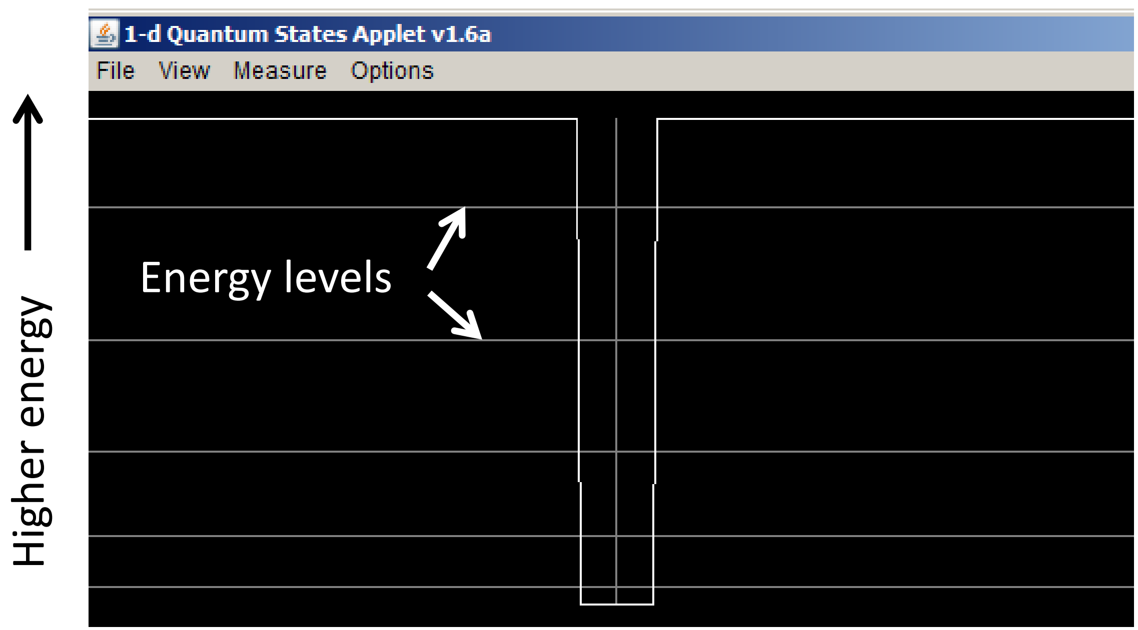
Origin of the Band Gap

Simulation of a **single energy well** (single atom) –

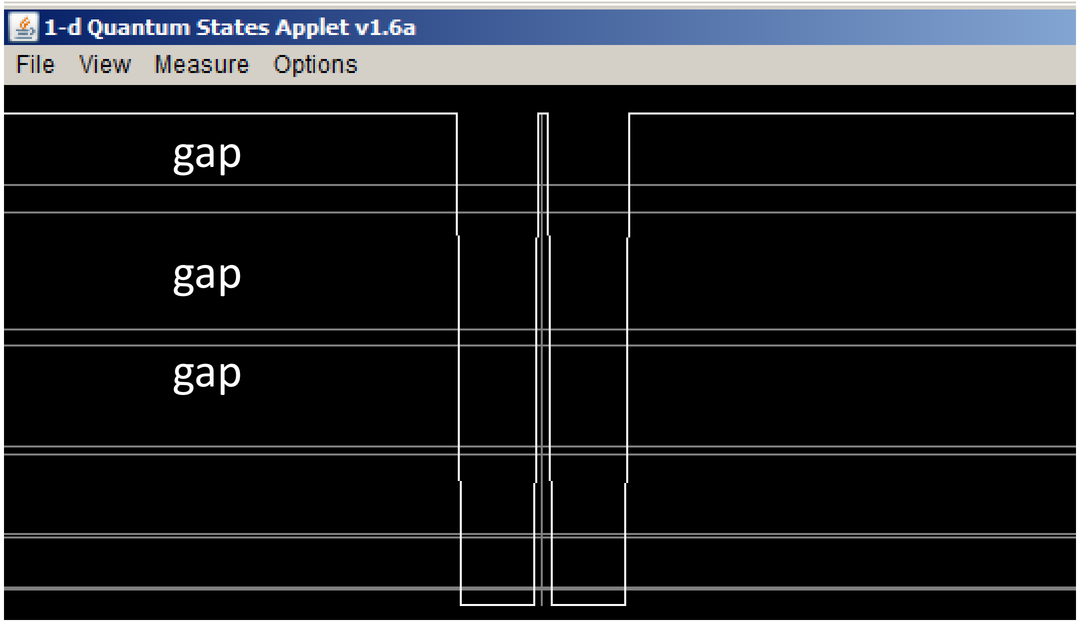
The result is a series of discrete energy levels



http://www.falstad.com/qm1d/

Origin of the Band Gap

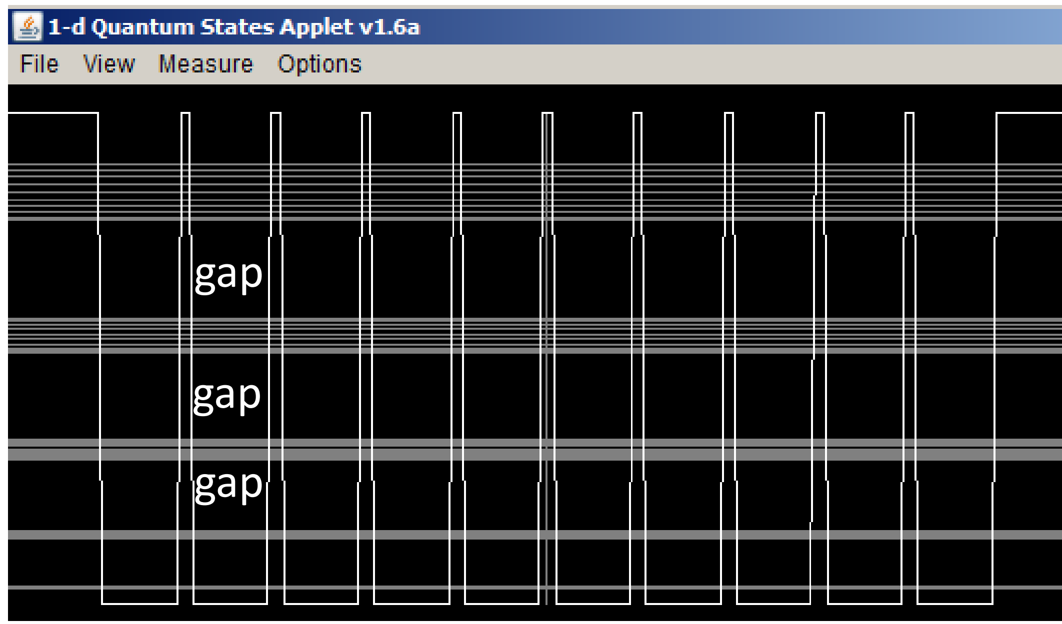
Several energy wells (molecule) –Each atomic level splits to closely spaced levels separated by gaps



Origin of the Band Gap

More atoms – levels merge into bands separated by gaps – As the number of atoms increase to macro size objects, the bands become dense continuous energy bands.

The in-between area where there are many atoms but the level density is not as great as a macro scale crystal is an area of intense research in areas such as quantum dots.



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Overview of Lab

In this investigation, we will utilize LED's both as light sources and light detectors to compare the band gaps between LED's that emit at different frequencies. We will also use a more intense red laser light source for comparison.

We will detect light by measuring the voltage generated in an LED when it is illuminated by light from another LED or the laser.

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Overview of Lab

		Detector					
		Energy					
		Color	IR	RED	YELLOW	GREEN	Blue
Illuminator	Energy	Color					
		IR					
		RED					
		YELLOW					
		GREEN					
		Blue					
		Laser Ptr					

Observations (voltage difference with/without illuminator)

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Working With LEDs

- LEDs as diodes – (long lead = +, short lead -)
- Show need for current limiting resistor (sacrifice an LED – optional)
- Options for using LEDs
  - Simple twist leads of LED and resistor or use clips
  - Solder LED and resistor
  - Build a small board

Simple soldering skills project (Solder LED and resistor; Build a small board)

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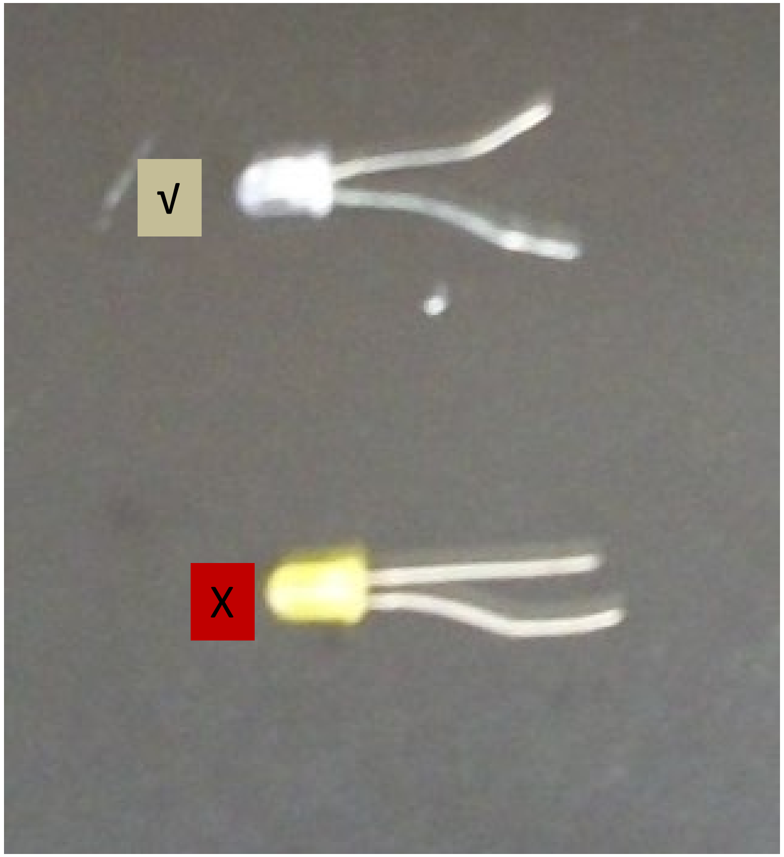
Working With LEDs

- Use LEDs with clear plastic cases
- Color cases add a confounding filtering effect
- Discussion point – Why?



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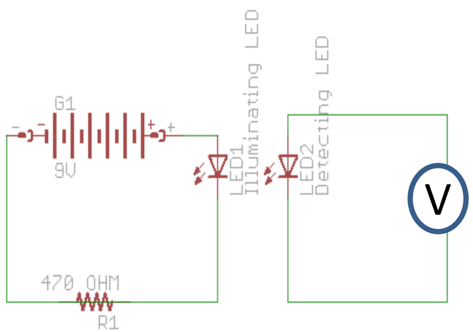
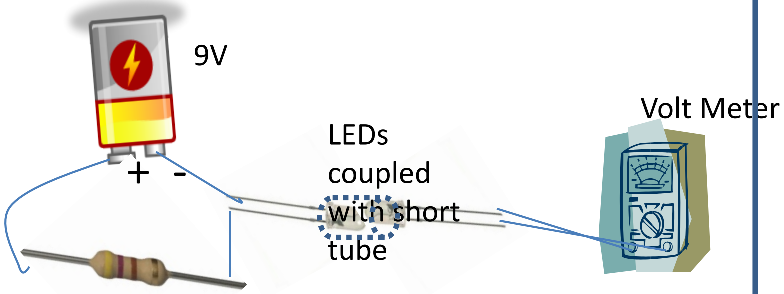
Circuit design and construction

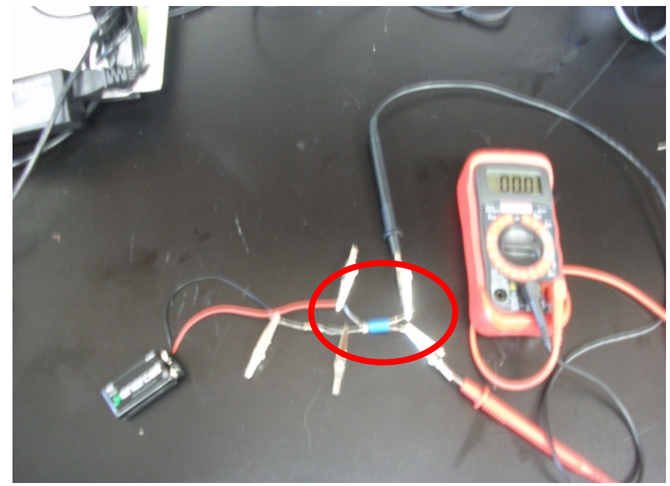
Schematic View



Pictorial View



Short LED lead goes to battery -



Use of a section
Of drinking straw or other tubing helps direct the light and exclude ambient light

Sample Results

		Detector					
		Energy					
		Color	IR	RED	YELLOW	GREEN	BLUE
Illuminator	Energy	Color					
		IR	.3V	0	0	0	0
		RED	.2V	.4V	o	0	0
		YELLOW	.2V	.2V	.3	.1???	0
		GREEN	.4V	.3V	.4	.2	0
		BLUE	.2V	.5V	.3V	.3V	.6V
		Laser Ptr (red)	.8V	.6V	0	0	0

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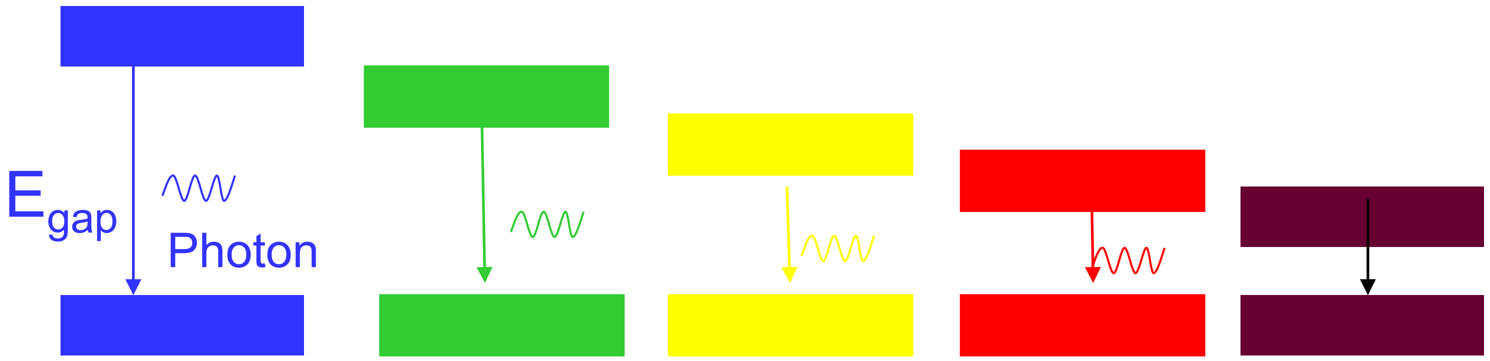
Explanation



For an LED with a given band gap energy, illuminating photon has to be greater than this energy to excite a signal.

Although green light is higher energy than yellow, we see a yellow LED does excite some signal in the green LED – LED colors are not sharp lines but bands, the yellow and green spectrum overlap.

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Extensions

- White and pink LEDs – view spectrum in a diffraction grating (or use a CD/DVD) and explain the use of phosphors
  - White LED's are actually blue LEDs with a phosphor added. For white LEDs the spectrum is rich in blue (LED) and yellow (phosphor) which together give a white appearance.
- Economic/Environmental impact of LED lighting -in references and additional material provided below

Supplementary source material on societal/environmental impacts

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Why LEDs?

- Typical household – 10%-15% of energy use is lighting
- CFL increase efficiency but they have mercury (small amounts)
- LEDs possible cleaner/more efficient alternative

Lighting Alternatives
Qualitative Assessment

	Efficiency	Cost	Spectrum flexibility	Life	Environmental Impact (fabrication materials)
Combustion	Abysmal	Low	Good	low	?
Incandescent	Low	Low	Good	low	Low
Fluorescent	Moderate	Moderate	Improving	moderate	moderate (mercury)
LED	Good	High but rapidly decreasing (as of 2012)	Improving	high	Low
Arc	Good	High	Good	low	Low

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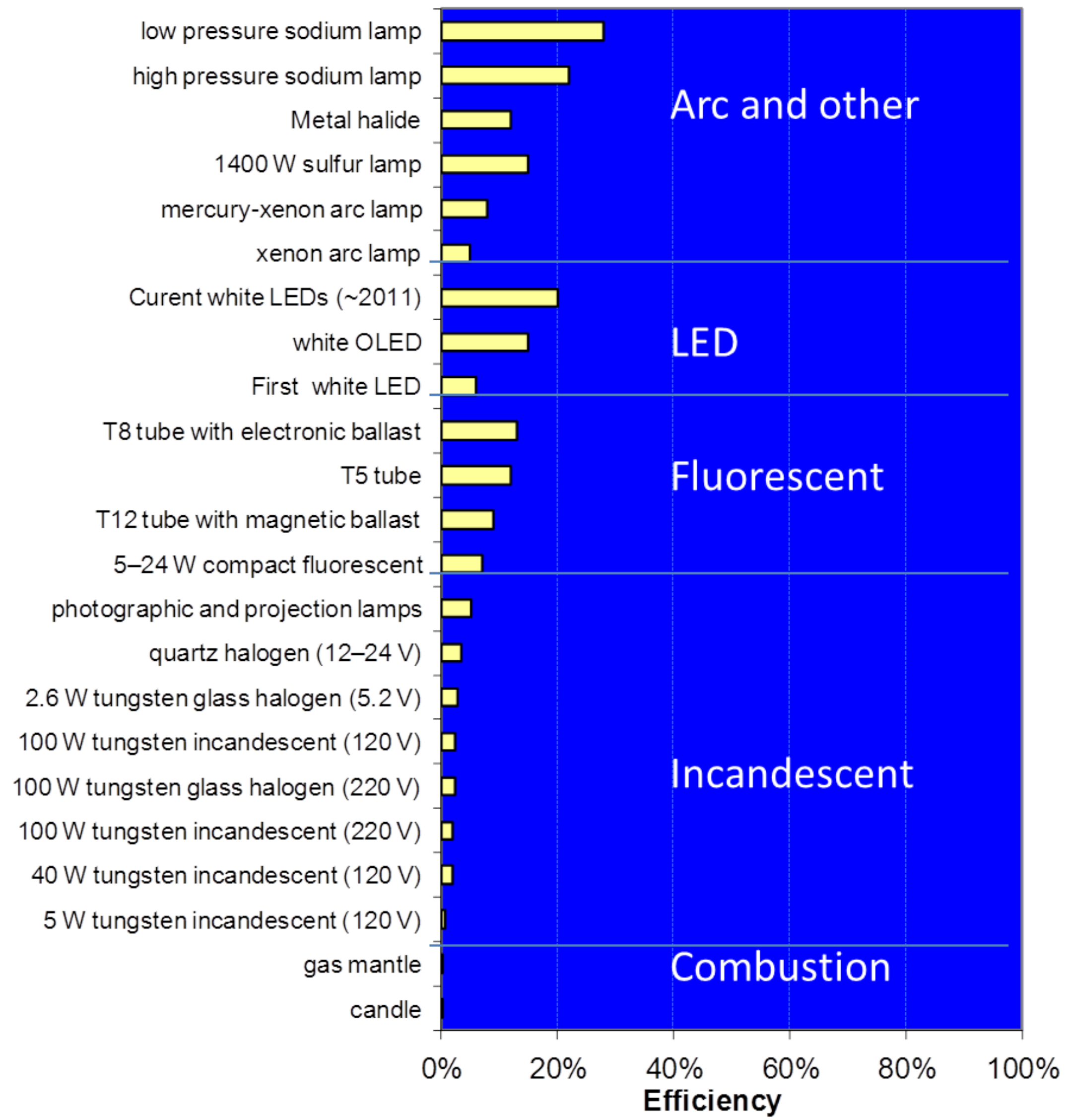
More quantitative 2012 view

Lighting Efficiency = Light energy out/Energy in



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Environmental Impact – Discussion Point

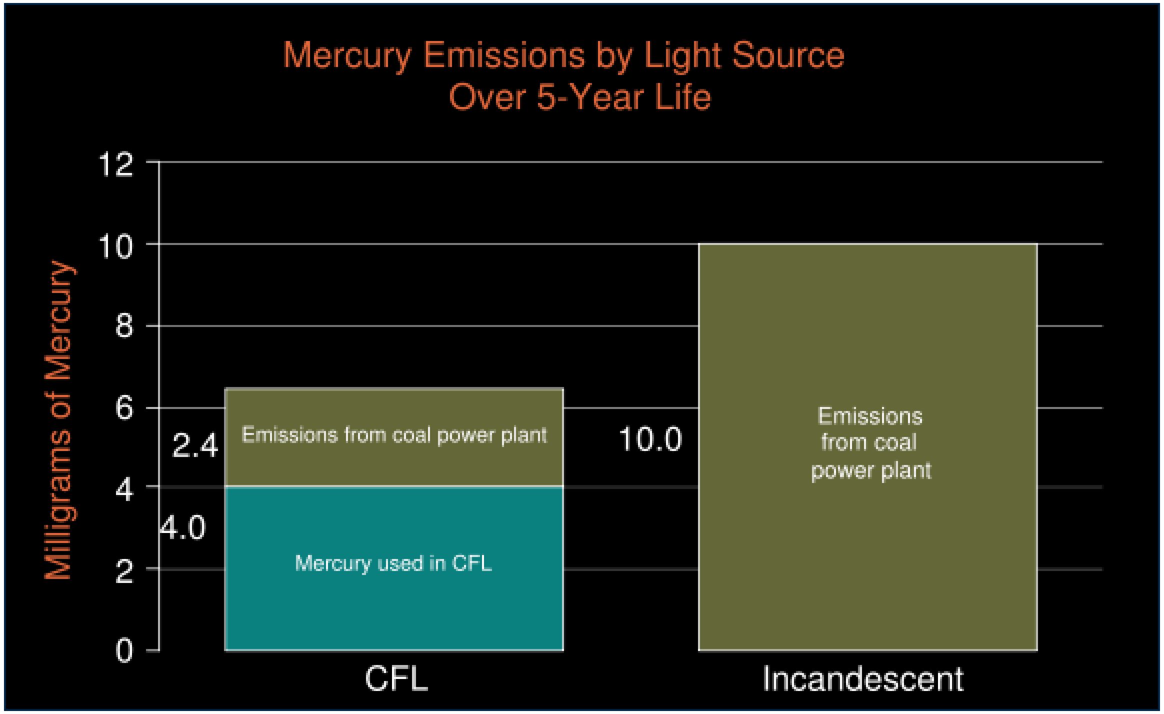
Claims and counterclaims about the net environmental impacts of CFL versus incandescent.

Points claimed:

•CFLs have mercury in them which can make its way into the environment upon disposal
•Burning coal releases mercury
•Because CFLs use less energy, less coal is burnt and less mercury released.
•On balance, this shows a net decrease in mercury released even if CFLs are not disposed of in a controlled manner
•LEDs are even cleaner – less coal burnt and no mercury

Complications and counterpoints

•CFL lifetime is less than advertised – more are thrown away. The chart at the right assumes 5 year life
•Semiconductor manufacturing techniques used to make LEDs have in the past been significant sources of pollution.
•Not all electricity is produced from coal



www.energytrust.org/.../cfl_mercury.html

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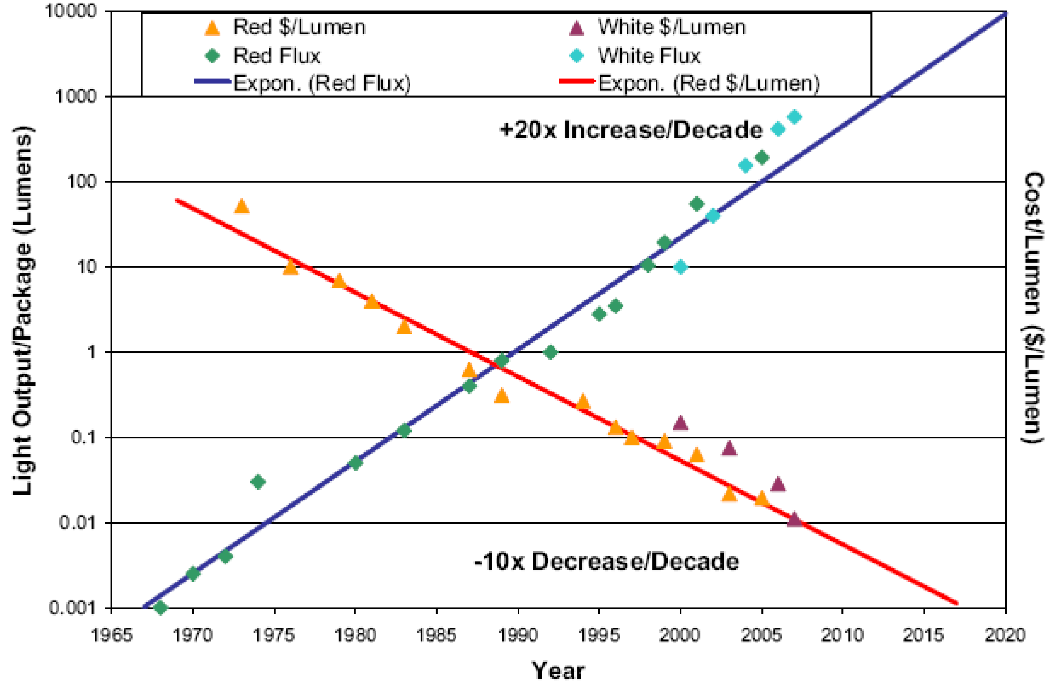
Haitz's Law:

Every decade, the cost per lumen falls by a factor of 10 and the amount of light generated per LED package increases by a factor of 20, for a given wavelength (color) of light



DOE 2008 Multiyear Program Plan

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International Agreements Affecting Energy Use

United Nations – Greenhouse Gas emissions

UNFCCC (United Nations Framework Convention on Climate Change),

Kyoto Protocol to the UNFCCC (Dec. 1997)

Decreasing CO_2(10 k ton/year, 2002 at Korea)

http://unfccc.int/

European Union

Waste Materials & Environmental Hazards

RoHS (Restriction of the use of Certain Hazardous Substance): 1, July 2006.

Pb, Hg, Cd, Cr^{6+}, Polybrominated biphenyls(PBB), Polybrominated diphenyl eters(PBDE)

WEEE (Electrical and Electronic Equipment)

Producer Responsibility

http://ec.europa.eu/

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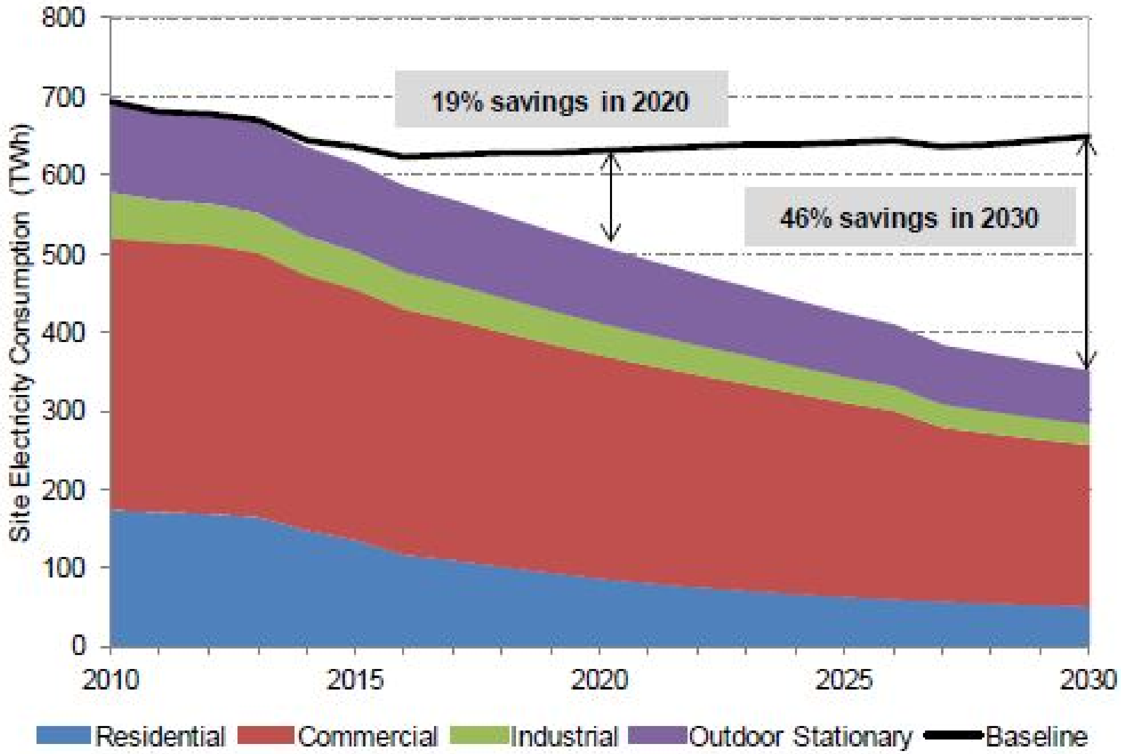
2012 US Department of Energy Forecast

Savings in lighting's energy use in the US if LED lighting is deployed as predicted (sloping curves) versus no additional LED deployment (baseline).



http://www1.eere.energy.gov/buildings/ssl/tech_reports.html

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Current uses of LEDs

- Commercial Lighting
  - Accent lighting
  - Environments where long life/low heat emission required
  - Matches well with low voltage alternative power sources (solar cells/wind/battery)

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Current uses of LEDs

- Residential Lighting
  - Available but somewhat more expensive (prices rapidly decreasing)
  - Generally “cool look” (too blue) appearance but color match to incandescent is rapidly improving.
  - Major lighting companies such as Philips have committed to making LEDs an affordable reality for the residential market.

Current uses of LEDs

- Automotive Lighting
  - First application – displays
  - In signal markers (brake/turn signals)
    - Long life (first used in truck/fleet vehicles)
  - Headlights now appearing – produce steerable arrays and fine tune lighting to ambient conditions

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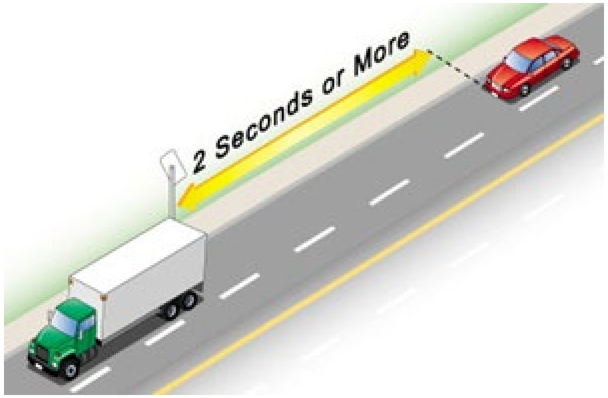
Increased safety with LED Brake lights

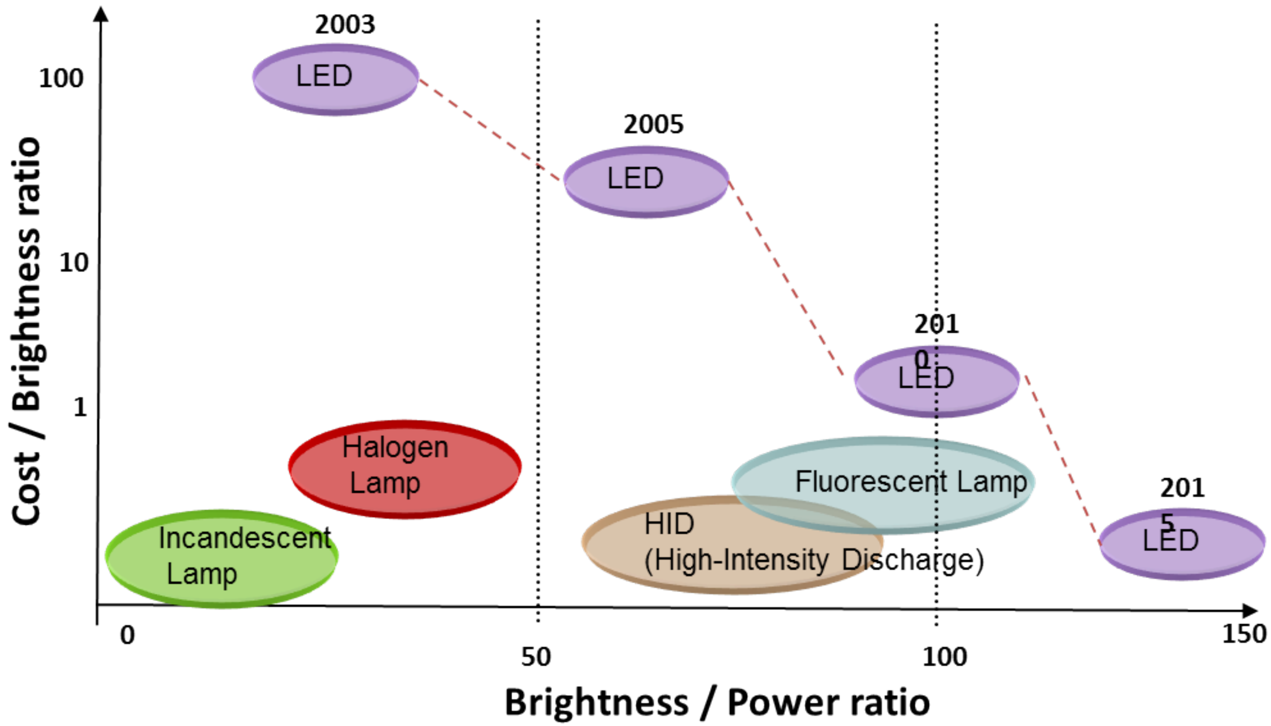
LED brake lights turn on approximately 250 milliseconds faster than incandescent brake lights

This gives the driver behind additional time and distance (25-30 feet at highway speed) to react to the vehicle in front.



LED technical evolution

❖ Performance and Price comparison



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Source: Credit Suisse, 2006.11.2

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