* Example of a Great Report

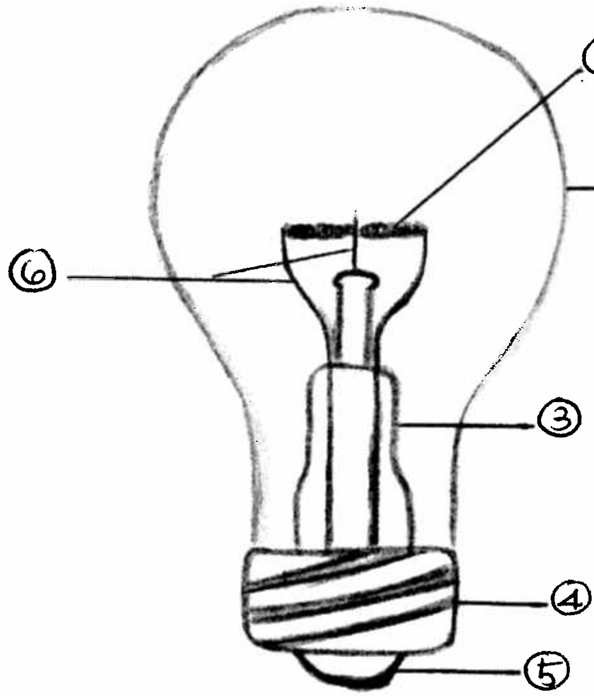
MSE 170 Lab 1 Report: What is it and Why

[redacted]

Lab procedure 1; light bulb exploration

Assembled sketch:

Only this sketch required



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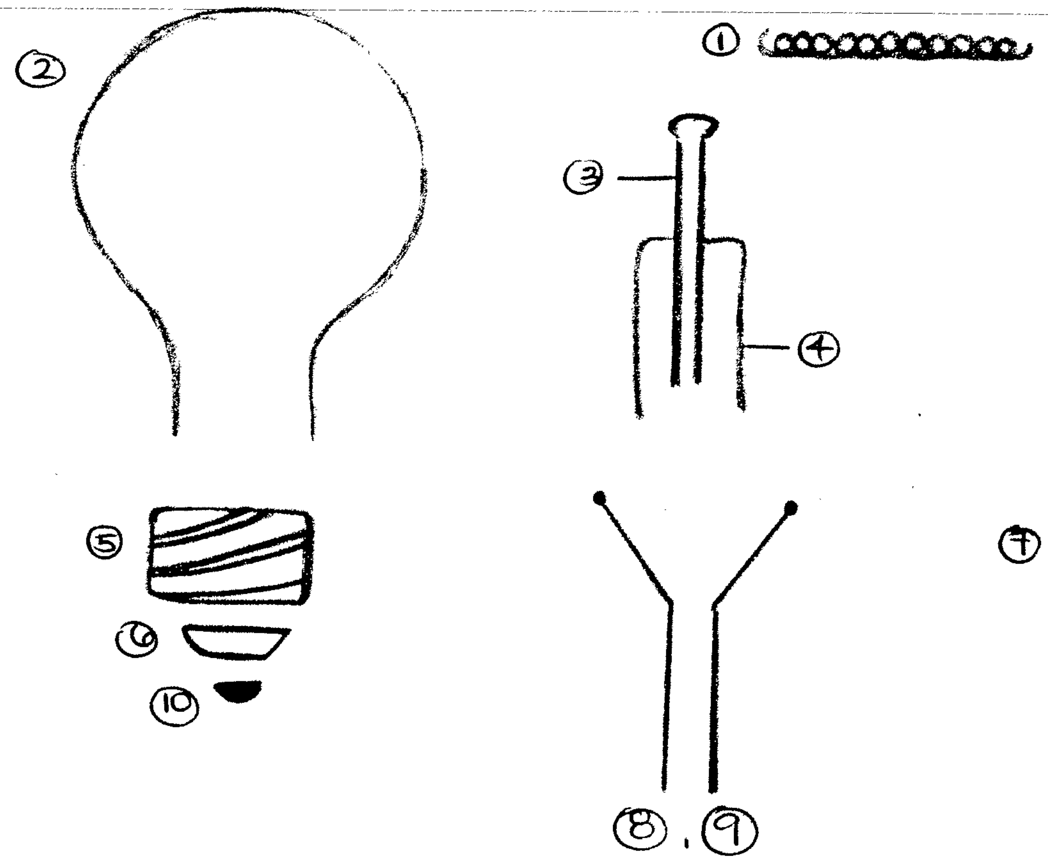
10 components

Component number	Name	Material	Properties	Processing Method
1	filament	tungsten	high heat resistance, electrically conductive	drawn wire
2	bulb	glass	clear, heat resistant, dielectric	heated/blown
3	post	glass	heat resistant, dielectric	heated/formed
4	cap	Metal possible tin	electrically conductive, inexpensive, corrosion resistant	stamped
5	contact	Metal possibly tin	electrically conductive, inexpensive, corrosion resistant	stamped
6	filament support	Metal/stainless	flexible, heat resistant	drawn wire

Table 1 (list of light bulb components before disassembly)

Exploded –view sketch:



Component number	Name	Material	Properties	Processing Method
1	filament	tungsten	high heat resistance, electrically conductive	drawn wire
2	bulb	glass	clear, heat resistant, dielectric	heated/blown
3	post	glass	heat resistant, dielectric	heated/formed
4	post base	glass	heat resistant, dielectric	Heated/blown
5	cap	Metal possibly tin	electrically conductive, inexpensive, corrosion resistant	stamped
6	contact	Metal possible tin	electrically conductive, inexpensive, corrosion resistant	stamped
7	filament support	metal/stainless	flexible, heat resistant	drawn wire
8	(+) contact wire	coated copper	electrically conductive,	drawn wire
9	(-) contact wire	coated copper	electrically conductive,	drawn wire
10	glue/dielectric	ceramic/composite	formable, good dielectric	solidified liquid

Table 2 (list of light bulb components after disassembly)

The light bulb is made of many different materials with various properties. The materials used vary from metals to ceramics to ultra clear glass. Each material used is selected for its individual properties according to the requirements of the given light bulb component. The electro-conductive path is made of metallic elements with low resistivity for high current flow. The filament is made of very fine Tungsten wire so as to have higher resistance than the rest of the electric circuit, creating friction, heat, and thus light. The bulb and other internal components of the bulb are constructed mostly of glass. This material provides very good light transmission for efficiency. Glass is also a near perfect dielectric, providing a good material to isolate the internal electric components of the bulb. Additional materials are used where needed, like the filament support and the dielectric 'glue' used to adhere the cap to the bulb.
The light bulb is an example of how a system requiring many different properties can be composed of different materials to meet the system needs.

good explanation

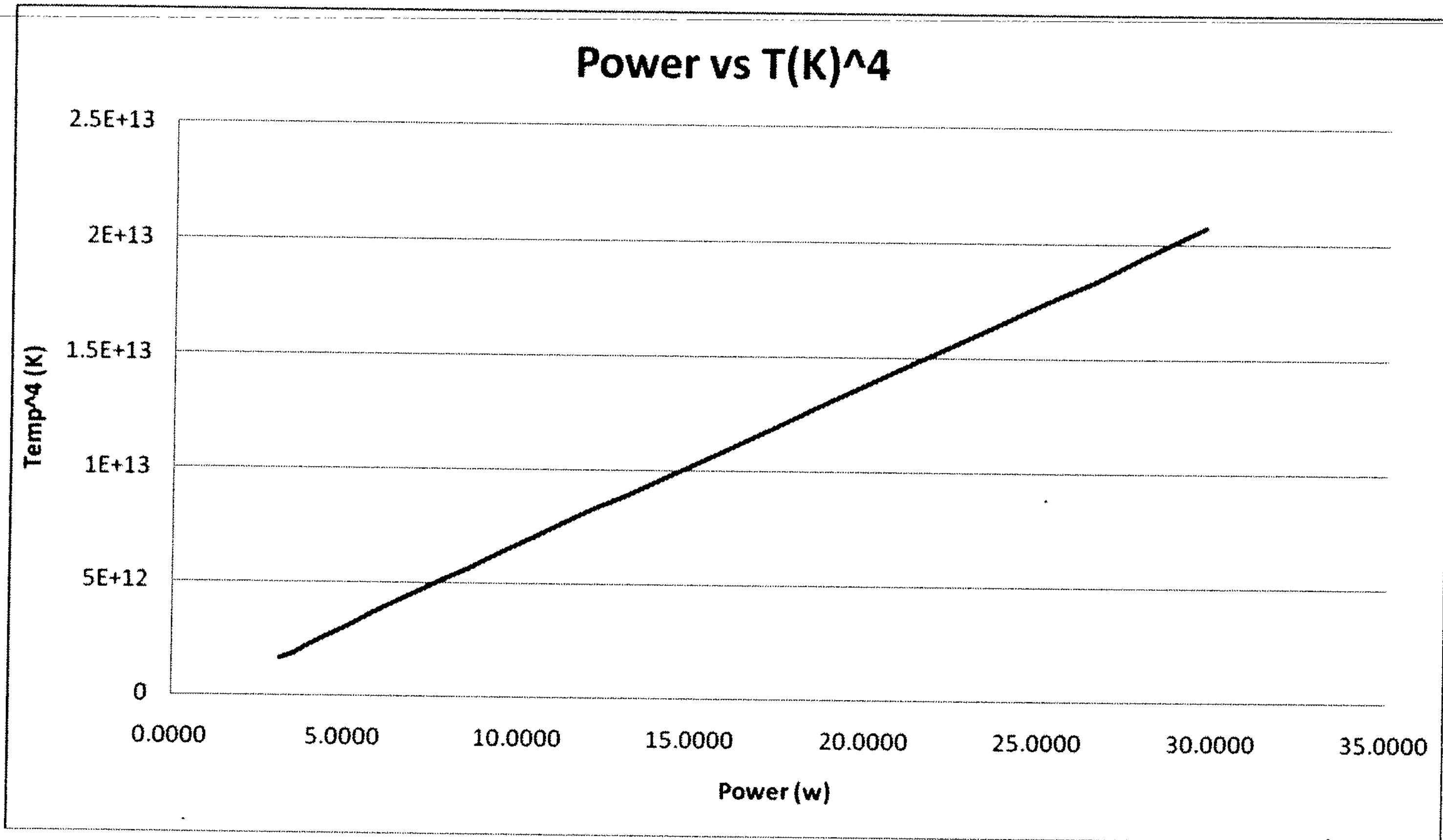
Procedure 2; Boltzmann constant exploration with a light bulb filament

The cold light bulb resistance as measured with a DMM. That resistance was found to be 27Ω. This value will be used as the reference room temperature resistance of the light bulb R(300), used below. The light bulb was then connected to a variable voltage input and the current was measured. The voltage was varied from about 20 volts where the light just turned on, up to about 95 volts (where the current was about 0.33 A) for safety. The resistance and power were calculated from the current and voltage by the equations $\Omega = \frac{Volt}{Amp}$, and $P = Volt * Amps$ respectively. These values are shown below in table 3. As expected and following with metallic element resistivity properties, the resistance and thus resistivity of the filament increased with temperature.

To explore the Boltzmann law of radiation, the power consumption and the effective temperature of the light bulb were compared. The law states that the power radiated is proportional to the absolute temperature to the fourth power. In the case of a light bulb, the power consumed is equal to the power radiated. The effective temperature of the light element was calculated and then cubed (table 3 below). The power consumption was plotted versus the fourth power of the temperature (graph 1 below). The plot showed a linear relationship between the power consumed and the temperature to the fourth power. This linear relationship confirms the Boltzmann radiation law for this light bulb element.

run number	current (A)	voltage (V)	Resistance(Ω)	r = R(T)/R(300)	T(K)=300*r^0.811	P=I*V	T(K)^4
1	0.1497	20.80	138.9446	5.1461	1132.7387	3.1138	1.64634E+12
2	0.1557	22.55	144.8298	5.3641	1171.4966	3.5110	1.88349E+12
3	0.1595	24.25	152.0376	5.6310	1218.5618	3.8679	2.20491E+12
4	0.1664	26.75	160.7572	5.9540	1274.9392	4.4512	2.64215E+12
5	0.1745	29.75	170.4871	6.3143	1337.1714	5.1914	3.19704E+12
6	0.1805	32.05	177.5623	6.5764	1382.0023	5.7850	3.64783E+12
7	0.1870	34.66	185.3476	6.8647	1430.9441	6.4814	4.19267E+12
8	0.1935	37.18	192.1447	7.1165	1473.3566	7.1943	4.71229E+12
9	0.1983	39.11	197.2264	7.3047	1504.8802	7.7555	5.12871E+12
10	0.2044	41.50	203.0333	7.5198	1540.7148	8.4826	5.63494E+12
11	0.2126	45.00	211.6651	7.8394	1593.6274	9.5670	6.44981E+12
12	0.2183	47.50	217.5905	8.0589	1629.7132	10.3693	7.05415E+12
13	0.2244	50.10	223.2620	8.2690	1664.0796	11.2424	7.66825E+12
14	0.2303	52.80	229.2662	8.4913	1700.2820	12.1598	8.35764E+12
15	0.2359	55.00	233.1496	8.6352	1723.6021	12.9745	8.82568E+12
16	0.2426	58.00	239.0767	8.8547	1759.0529	14.0708	9.57449E+12
17	0.2518	62.40	247.8157	9.1784	1811.0221	15.7123	1.07571E+13
18	0.2568	64.90	252.7259	9.3602	1840.0691	16.6663	1.1464E+13
19	0.2630	68.00	258.5551	9.5761	1874.4155	17.8840	1.23442E+13
20	0.2670	70.00	262.1723	9.7101	1895.6542	18.6900	1.29133E+13
21	0.2725	72.80	267.1560	9.8947	1924.8263	19.8380	1.37267E+13
22	0.2767	75.00	271.0517	10.0390	1947.5584	20.7525	1.43867E+13
23	0.2806	77.00	274.4120	10.1634	1967.1167	21.6062	1.49734E+13
24	0.2846	79.20	278.2853	10.3069	1989.6050	22.5403	1.56699E+13
25	0.2900	82.00	282.7586	10.4725	2015.5032	23.7800	1.65019E+13
26	0.2936	84.00	286.1035	10.5964	2034.8181	24.6624	1.71436E+13
27	0.2972	86.00	289.3674	10.7173	2053.6239	25.5592	1.77862E+13
28	0.3010	88.00	292.3588	10.8281	2070.8243	26.4880	1.83896E+13
29	0.3061	91.00	297.2885	11.0107	2099.0977	27.8551	1.94147E+13
30	0.3130	95.00	303.5144	11.2413	2134.6792	29.7350	2.07649E+13

Table 3 (table of measured I and V and calculated Ω, r, T(K) at operating temp, power, and T(K) ^4))



Graph 1 (Power in watts vs Temp^4) in Kelvin))

✓

— Good — explanations are clear

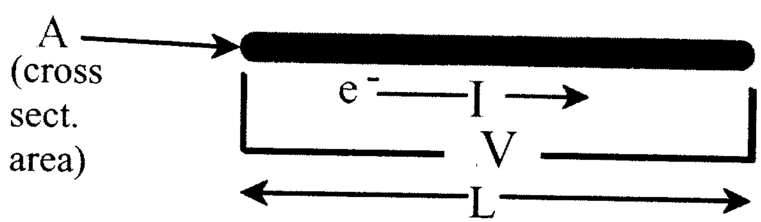
100%

$$V = I\,R$$

voltage drop (volts) → V; current (amps) → I; resistance (Ohms) → R

- Resistivity, ρ and Conductivity, σ:

--geometry-independent forms of Ohm's Law



$$\frac{V}{L} = \frac{I}{A}\,\frac{R}{L}A$$

E: electric field intensity → $\frac{V}{L}$

J: current density → $\frac{I}{A}$

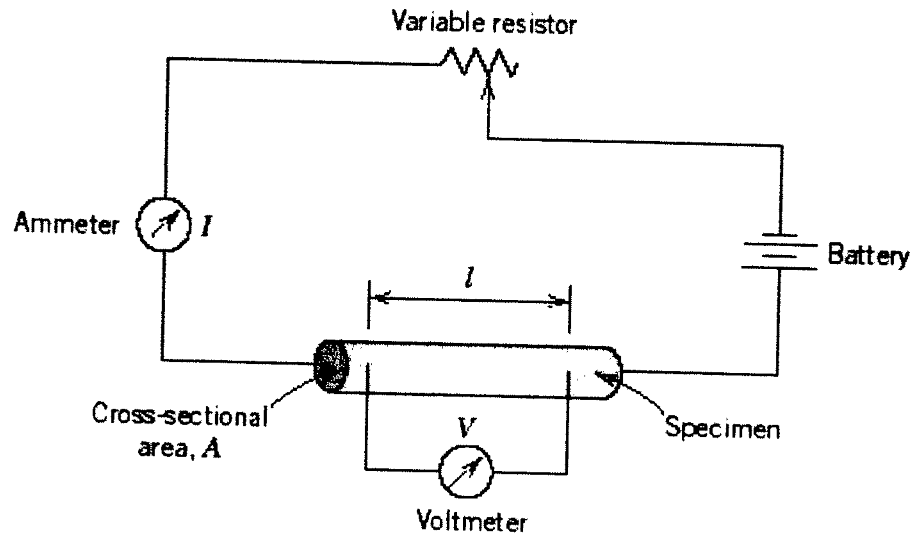
resistivity (Ohm-m) → $\frac{R}{L}A$ $\quad \rho$

- Resistance: $R = \frac{\rho L}{A} = \frac{L}{A\sigma} \quad \frac{\Delta V}{L} = \frac{I}{A}\rho$

conductivity → $\sigma = \frac{1}{\rho}$

ELECTRICAL CONDUCTION

- Ohm's Law:



$$V = I\,R$$

voltage drop (volts) → V; current (amps) → I; resistance (Ohms) → R

MSE 170 Summer-2007

Materials Science and Engineering of Light Bulb

History of Incandescent Bulbs

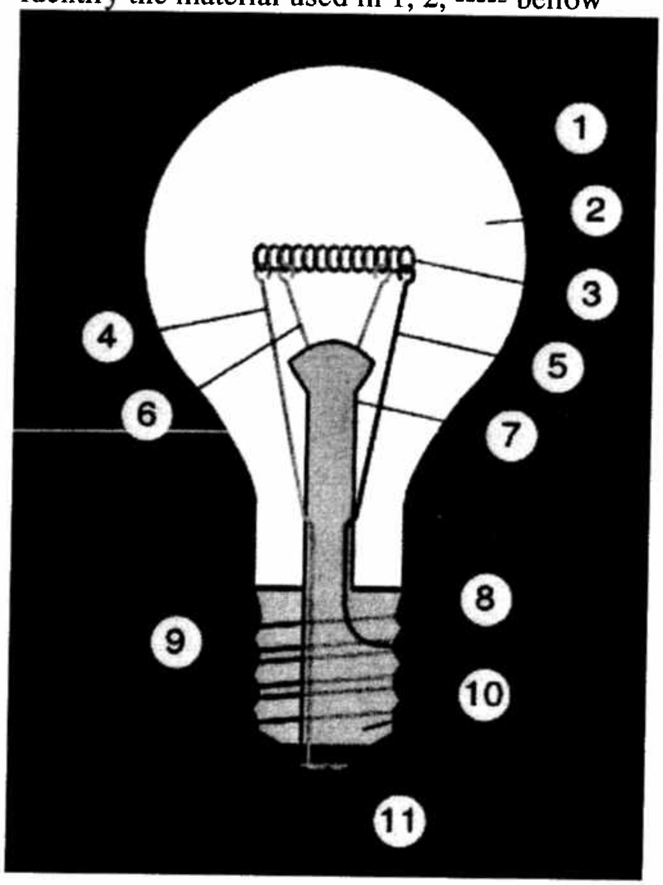
1. Invented by Thomas Alva Edison in 1879. Used a **carbonized bamboo filament** in a bulb containing a vacuum. Lasted up to 400 hours.

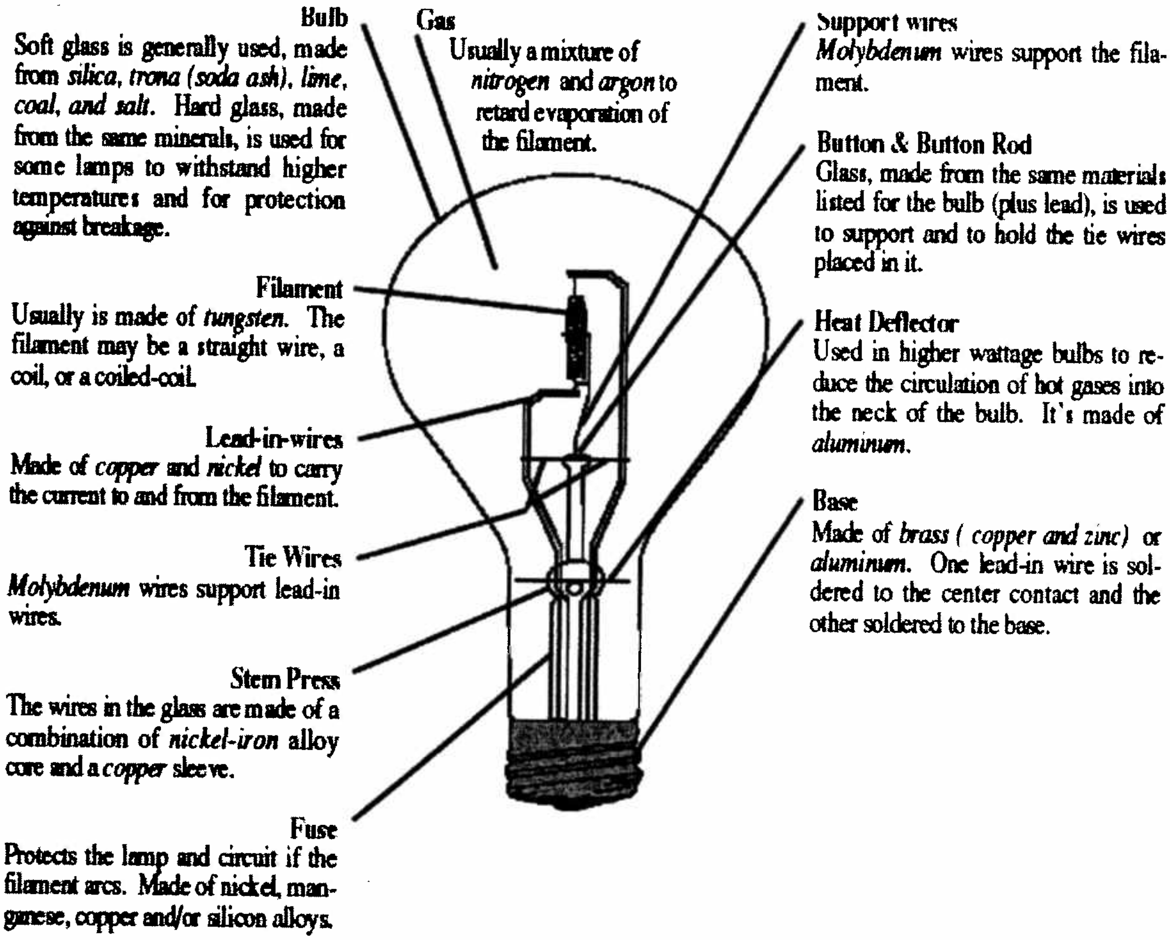
2. Earlier attempts:
   Heinrich Goebel made with a carbon filament in 1854. Joseph Wilson Swan made carbon-based incandescent lamps in 1850 and made one in 1860 that was workable except for excessively short life due to poor vacuum. He made more successful inccandescent lamps after better vacuum pumps became available in the mid 1870's.

3. Since that time, the incandescent lamp has been improved by using **tantalum** and later **tungsten** filaments, which evaporate more slowly than carbon. Nowadays, incandescent lamps are still made with **tungsten** filaments.

Structure of Light Bulb

Identify the material used in 1, 2, ----- bellow





Basic Principles

1. The filament of an incandescent lamp is simply a **resistor**. Electrical power is converted to **heat** in the filament whose temperature rises until it gets rid of heat at the same rate that heat is being generated in the filament. Ideally, the filament gets rid of heat only by radiating it away, however, a small amount of heat energy is also removed from the filament by thermal conduction.

2. The filament's temperature is very generally over 2000°C (or 3600 °F).

3. In a "standard" 75~100 watt 120 volt bulb, the filament temperature is roughly 2550°C (or 4600 °F). At high temperatures like this, the thermal radiation from the filament includes a significant amount of visible light. **Why?**

Luminous Efficiency

1. Rated output for a 100 watt "standard" bulb (120V operation) = 1750 lumens.
   Efficiency = 17.5 lumens per watt.

2. Most household incandescent bulbs have efficiencies from 8 to 21 lumens per watt. Higher efficiencies near 35 lumens per watt are only achieved with photographic and projection lamps with very high filament temperatures and short lifetimes of a few hours to around 40 hours.

3. Comparison:

- 242.5 lumens per watt for one idealized type of white light
- 683 lumens per watt for the yellowish-green wavelength of light that the human eye is most sensitive to.

4. Why is the light bulb poor in its efficiency?
Tungsten filaments radiate mostly infrared (IR) radiation at any temperature that they can withstand.

5. An ideal thermal radiator produces visible light most efficiently at temperatures around 6300°C (6600 K or 11,500 F). Even at this high temperature, a lot of the radiation is either **infrared** or **ultraviolet**, and the theoretical luminous efficiency is 95 lumens per watt.

Vacuum vs. gas-filled bulbs

1. First incandescent bulbs were made with a vacuum inside them, but even in vacuum, residual gas molecules can oxidize the filament at high temperatures.

2. Later, the bulb is filled with an inert gas such as argon or an argon-nitrogen mixture, slowing down evaporation of the filament.

3. Tungsten atoms evaporating from the filament can be bounced back to the filament by gas atoms. The filament can be operated at a higher temperature with a fill gas than with a vacuum. This results in more efficient radiation of visible light.

4. Why are some bulbs still made with a vacuum?
A fill gas conducts heat away from the filament. This conducted heat is energy that cannot be radiated by the filament and is lost, or wasted. This mechanism reduces the bulb's efficiency of producing radiation. If this is not offset by the advantage of operating the filament at a higher temperature, then the bulb is more efficient with a vacuum.

5. The amount of heat conducted from the filament to the gas is roughly proportional to the filament's length, but does not vary much with the filament's diameter.

This means that bulbs with thin filaments and lower currents are more efficient with a vacuum, and ones with thicker filaments and higher current are more efficient with a filled gas.

The break-even point seems to be very roughly around 6-10 watts per centimeter of filament. Sometimes, premium fill gases such as **krypton** or **xenon** are used. These gases have larger atoms that are better at bouncing evaporated tungsten atoms back to the filament. These gases also conduct heat less than argon. Of these two gases, xenon is better, but more expensive. Either of these gases will significantly improve the life of the bulb, or result in some improvement in efficiency, or both. Often, the cost of these gases makes it uneconomical to use them.

How light bulbs burn out

1. Due to the high temperature that a tungsten filament is operated at, some of the tungsten evaporates during use.

2. Since no light bulb is perfect, the filament does not evaporate evenly. Some spots will suffer greater evaporation and become thinner than the rest of the filament.

3. These thin spots cause problems, causing sudden increase of the electrical resistance, creating more heat in thinner filament region. The thin parts also have less surface area to radiate heat away with. This "double whammy" causes the thin spots to have a higher temperature. Now that the thin spots are hotter, they evaporate more quickly.It becomes apparent that as soon as a part of the filament becomes significantly thinner than the rest of it, this situation compounds itself at increasing speed until a thin part of the filament either melts or becomes weak and breaks.

Why bulbs often burn out when you turn them on

1. You may wonder why bulbs often burn out when you turn them on.

2. The answer here is with those thin spots in the filament. Since they have less mass than the less-evaporated parts of the filament, they heat up more quickly. Part of the problem is the fact that tungsten, like most metals, has less resistance <u>when it is cool and more resistance when it is hot</u>. This explains the current surge that light bulbs draw when they are first turned on.

3. When the thin spots have reached the temperature that they would be running at, the thicker, heavier parts of the filament have not yet reached their final temperature. This means that the filament's resistance is still a bit low and excessive current is still flowing. This causes the thinner parts of the filament to get even hotter while the rest of the filament is still warming up.This means that the thin spots, which run too hot anyway, get even hotter when the thicker parts of the filament have not yet fully warmed up. This is why weak, aging bulbs can't survive being turned on.

Why burnout is sometimes so spectacular

1. When the filament breaks, an arc sometimes forms. Why?

2. Since the current flowing through the arc is also flowing through the filament at this time, there is a voltage gradient across the two pieces of the filament. This voltage gradient often causes this arc to expand until it is across the entire filament.

3. Now, consider a characteristic of most electric arcs. If you increase the current going through an arc, it gets hotter, which makes it more conductive. Obviously, this could make things a bit unstable, since the more conductive arc would draw even more current. The arc easily becomes conductive enough that it draws a few hundred amps of current. At this point, the arc often melts the parts of the filament that the ends of the arc are on, and the arc glows with a very bright light blue flash.

4. Most household light bulbs have a built-in fuse, consisting of a thin region in one of the internal wires. The extreme current drawn by a burnout arc often blows this built-in fuse. If not for this fuse, people would frequently suffer blown fuses or tripped circuit breakers from light bulbs burning out.Although the light bulb's internal fuse will generally protect household fuses and circuit breakers, it may fail to protect the more delicate electronics often found in light dimmers and electronic switching devices from the current surges drawn by "burnout arcs".

Making bulbs last longer

1. Long-life bulbs: Many light bulbs are made to operate with a slightly lower filament temperature than usual. This makes the bulbs last much longer with a slight reduction of efficiency.

2. Reduced Power: Reducing the voltage applied to a light bulb will reduce the filament temperature, resulting in a dramatic increase in life expectancy.

3. Soft-start devices: Since bulbs usually burn out during the current surge that occurs when they are turned on, one would expect that eliminating the surge would save light bulbs.In fact, such devices are available in a form that is built into caps that one could stick onto the tip of the base of a light bulb.

   These devices are called "**negative temperature coefficient thermistors**", which are resistors having a resistance that decrease when they heat up.When the bulb is first started, the thermistor is cool and has a moderately high resistance that limits current flowing through the bulb. The current flowing through the thermistor's resistance generates heat, and the thermistor's resistance decreases. This allows the current to increase in a fairly gradual manner, and the filament warms up in a uniform manner.

   However, this extends the life of the bulbs less than one might think. If the filament has thin spots that cannot survive the current surge that occurs when the bulb is turned on, then the filament is already in very bad shape. At this time, the thin spots are significantly hotter than the thicker parts of the filament and are evaporating rather rapidly. As described earlier, this process is accelerating. If the thin spots are protected from surges, the life of the bulb would be extended by only a few percent. Additional life extension occurs only because the thermistor keeps enough resistance to result in enough heat to keep it fairly conductive. This resistance slightly reduces power to the bulb, extending its life somewhat and making it slightly dimmer.

DC vs. AC operation

1. As tungsten atoms evaporate from the filament, a very small percentage of them are ionized by the small amounts of short-wave ultraviolet light being radiated by the filament, the electric field around the filament, or by free electrons that escape from the filament by thermionic emission.

2. These tungsten ions are positively charged, and tend to leave the positive end of the filament and are attracted to the negative end of the filament. The result is that light bulbs operated on DC have this specific mechanism that would cause uneven filament evaporation.This mechanism is generally not significant, although it has been reported that light bulbs sometimes have a slight, measurable decrease in lifetime from DC operation as opposed to AC operation.

3. In a few cases, AC operation may shorten the life of the bulb, but this is rare. In rare cases, AC may cause the filament to vibrate enough to significantly shorten its life. In a few other rare cases involving very thin filaments, the filament temperature varies significantly throughout each AC cycle, and the peak filament temperature is significantly higher than the average filament temperature.Ordinarily, one should expect a light bulb's life expectancy to be roughly equal for DC and AC.

Why making bulbs last longer often does not pay

1. Life expectancy of a light bulb $\sim 1/V^{12\sim13}$.

2. Power consumption $\sim V^{1.4\sim1.55}$

3. Light output $\sim V^{3.1\sim3.4}$

4. Luminous $\sim V^{1.55\sim2.0}$

5. Now, if a slight reduction in applied voltage results in a slight to moderate loss of efficiency and a major increase in lifetime.

6. How could this cost you more? The answer is in the fact that the electricity consumed by a typical household bulb during its life usually costs many times more than the bulb does. Bulbs are so cheap compared to the electricity consumed by them during their lifetime that it pays to make them more efficient by having the filaments run hot enough to burn out after only several hundred to about a thousand hours or so.

An example with actual numbers

1. Suppose you have 10 "standard" 100 watt 120 volt bulbs with a rated lifetime of 750 hours.

2. Such bulbs typically cost around 75 cents in the U.S. The electricity used by all ten of these bulbs is 1 kilowatt, which would typically cost about 9 cents per hour (approximate U.S. average).

3. Over 750 hours, this would cost (on an average) $67.50 for the electricity plus $7.50 for 10 bulbs, or $75.

4. Now, suppose you use these bulbs with 110 volts instead of 120.These bulbs would consume about 87.8 watts instead of 100. However, they would only produce 76 percent of their normal light output. To restore the original light output, you need additional 3 of these bulbs. Using 13 bulbs that consume 87.8 watts a piece results in a power consumption of 1141 watts. Over 750 hours at 9 cents per KWH, this would cost $77. This is more than the $75 cost of running 10 bulbs at full voltage even if the bulbs never burn out at 110 volts. On the other hand, at 110 volts instead of 120, the life expectancy of the bulbs may be tripled. One third of 13 times 75 cents is about $3.25, which adds to the $77 cost of electricity to result in an average total cost of $80.25 for 750 hours.

5. This example should explain why you often get the most light for the least money using standard bulbs rather than longer-lasting ones.

How to minimize lighting costs

1. Higher wattage bulbs tend to be more efficient than lower wattage ones.

2. One reason for this is the fact that thicker filaments can be operated at a higher temperature, which is better for radiating visible light.Another reason is that since higher wattage bulbs would lead you to use fewer bulbs, you buy fewer bulbs and the cost of bulbs becomes less important. To optimize cost effectiveness in this case of higher wattage light bulbs, the filaments are designed to run even hotter to improve energy efficiency to reduce your electricity costs.Smaller bulbs use less electricity apiece, making the cost of the bulb more important. This is why lower wattage bulbs are often designed to last 1500 to a few thousand hours instead of 750 to 1000 hours. Designing the bulbs to last longer reduces their light output and energy efficiency.

3. To minimize your cost of both electricity and bulbs, you should use as few bulbs as possible, using higher wattage bulbs. To get the same amount of light with lower wattage bulbs, you need both more electricity and more bulbs.

5. An even better way to reduce your lighting costs is to use fluorescent, compact fluorescent, or HID (mercury, metal halide, or sodium) lamps since these are 3 to 5 times as efficient as incandescent lamps.

Halogen Bulbs

The halogen cycle, What are halogen bulbs?

1. A halogen bulb is an ordinary incandescent bulb, with a few modifications. The fill gas includes traces of a halogen, often but not necessarily iodine. The purpose of this halogen is to return evaporated tungsten to the filament.As tungsten evaporates from the filament, it usually condenses on the inner