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RM061

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# Snap Circuits Part 3: Optical Communications

**The Photophone: A Wireless Breakthrough**

In the summer of 1880, Alexander Graham Bell and associate Charles Sumner Tainter invented the revolutionary "photophone." This groundbreaking invention harnessed the concept of using sound waves to modulate a beam of light to transmit Morse code, voice and other sounds over line-of-sight distances reaching 213 metres (Figure 1).

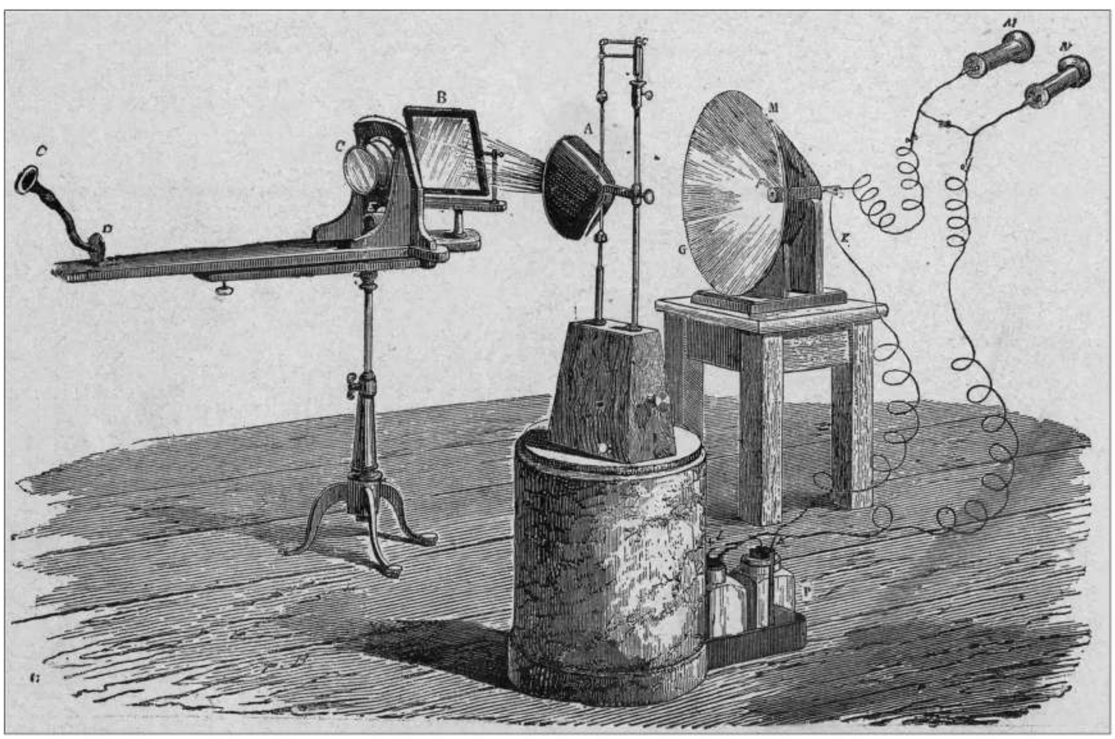


**Figure 1: The Photophone (1880)**

Credit: Getty Images.

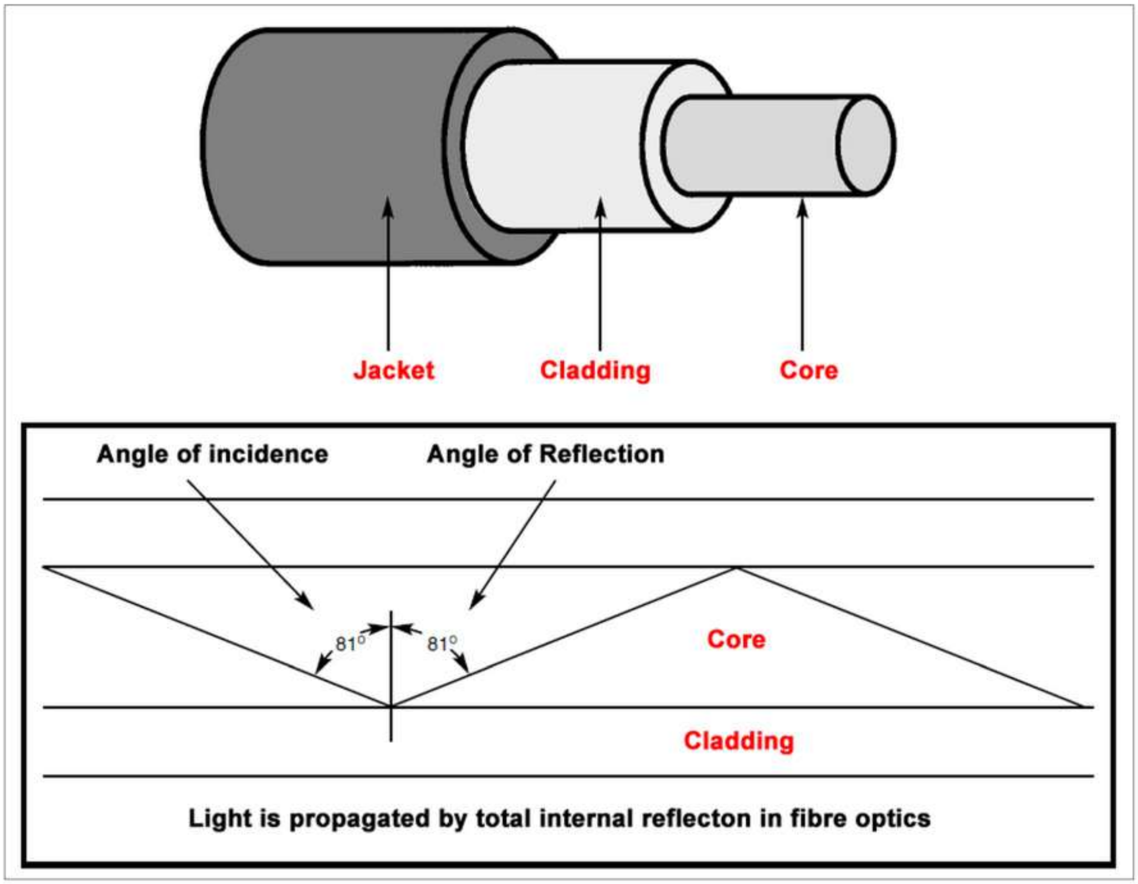
Bell considered it to be a greater invention than his telephone, and was so enthralled that he wanted to name his newborn daughter “Photophone”, but his wife thought otherwise. Bell also wrote an enthusiastic letter to his father announcing the birth. "I have heard articulate speech by sunlight! I have heard a ray of the sun laugh and cough and sing! I have been able to hear a shadow and I have even perceived by ear to the passage of a cloud across the sun's disk. You are the grandfather of the Photophone and I want to share the delight of my success. Can imagination even picture what the future of this invention is to be? We may talk by light to any visible distance without any conduction wire. In general science, discoveries will be made by the photophone that are undreamed of just now." But the press was not so enthused. The New York Times, in an August 1880 editorial, noted derisively: "The ordinary man will find a little difficulty in comprehending how sunbeams are to be used. Does Prof. Bell intend to connect Boston and Cambridge by a man going through the streets carrying a coil of No. 12 sunbeams on his shoulder, suspending them from telegraph pole to pole? There will be a general feeling that there is something about Prof. Bell's photophone which places a tremendous strain on human credulity."

The photophone had obvious limitations; it required a careful and rock steady alignment between the line-of-sight transmitter and receiver; it depended on sunlight or some other intense light source plus it didn’t work very well or not all in bad weather conditions. It was a successful failure because it was born a century too early and because of the birth of another form of wireless communications called “radio”. But Bell’s concept of using light to transfer information from point A to point B laid the groundwork for today’s optical communications systems because, in the 21$^{st}$ century, well over 90% of the world’s analog/digital voice and data are transported around the planet using beams of laser light reflecting over and over again along bundles of hundreds or even thousands of very thin, glass-spun fibre optic cables (Figure 2, next page) laid overland or on the bottom of rivers, seas and oceans.

As an aside, the photophone was modified in 1881 and this derivation was called the “spectrophone”, a device for the spectral analysis of sound waves. We can download the modern equivalent software application for use with our smartphones.

**Figure 2: Fibre Optic Cable Structure**

Credit: Elenco Electronics.




*Note: Well known Radio Shack author Forest Mims III "Engineer's Mini-Notebook: Communications Projects" (*https://tinyurl.com/4befs934*) and also "Optoelectronics Circuits" (*https://tinyurl.com/bdfz2twt*) has written a light wave communications tutorial plus created several circuits that you can build including a modern electronic version of Bell's photophone that easily outperforms the original.*

**What is Light, Actually?**

In 1666, Isaac Newton used prisms to split sunlight into the colours of rainbow, which he believed to be composed of particles he called "corpuscles". His corpuscular or particle theory explained why light travels in straight, parallel rays (rectilinear) as well as reflection and refraction. But another rival genius, astronomer Christiaan Huygens, disagreed because his experiments revealed its wave-like behaviours such as

polarization plus interference and diffraction patterns. How could both theories be right? How could light be both a wave and a particle at the same time?
*Note: The major colour divisions produced by a prism are defined today as: red, orange, yellow, green, blue, indigo and violet (or "Roy G. Biv" for physics tests). This is also the order of their energy levels from lowest to highest, and their wavelengths from longest to shortest (Figure 3A). However, unlike prisms, our analog eyes blend the analog colour continuum instead of producing sharp digital divisions so we can distinguish many more of shades of "colour" than just the prism's seven!*

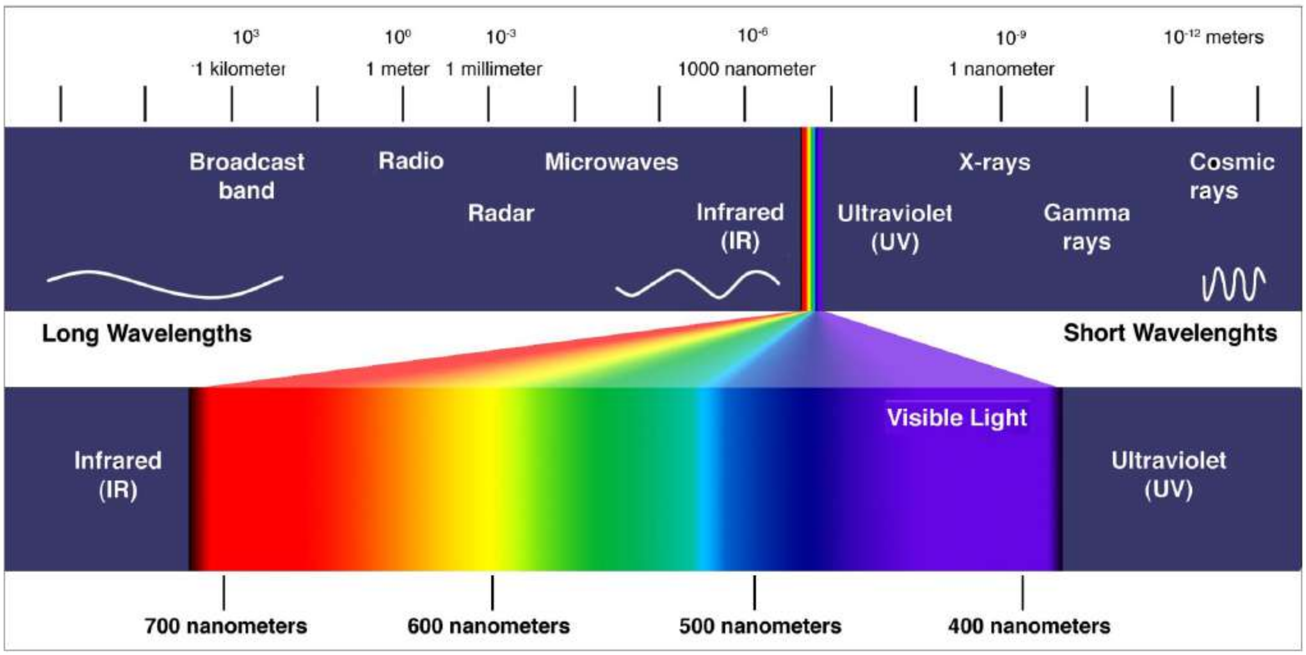



**Figure 3A: The EM Spectrum**
Credit: NASA/NOAA.

In 1864, James Clerk Maxwell unified the electric and magnetic field and force laws of Gauss, Ampere and Faraday, proving that the once thought separate forces of electricity and magnetism—including light—were all manifestations of one electromagnetic (EM) fundamental force. Maxwell's equations (they are actually Oliver Heaviside's reworking of the original, very convoluted eight algebraic equations using eight variables) famously predicted that changing/oscillating electric and magnetic fields generate a traverse EM wave that propagates at the speed of light in a vacuum (Figure 3B, next page). But no one could prove that Maxwell's theoretical EM waves existed until the late 1880's when Heinrich Hertz conducted a series of experiments generating and detecting them in the laboratory as well as confirming Maxwell's predicted properties of the EM waves.

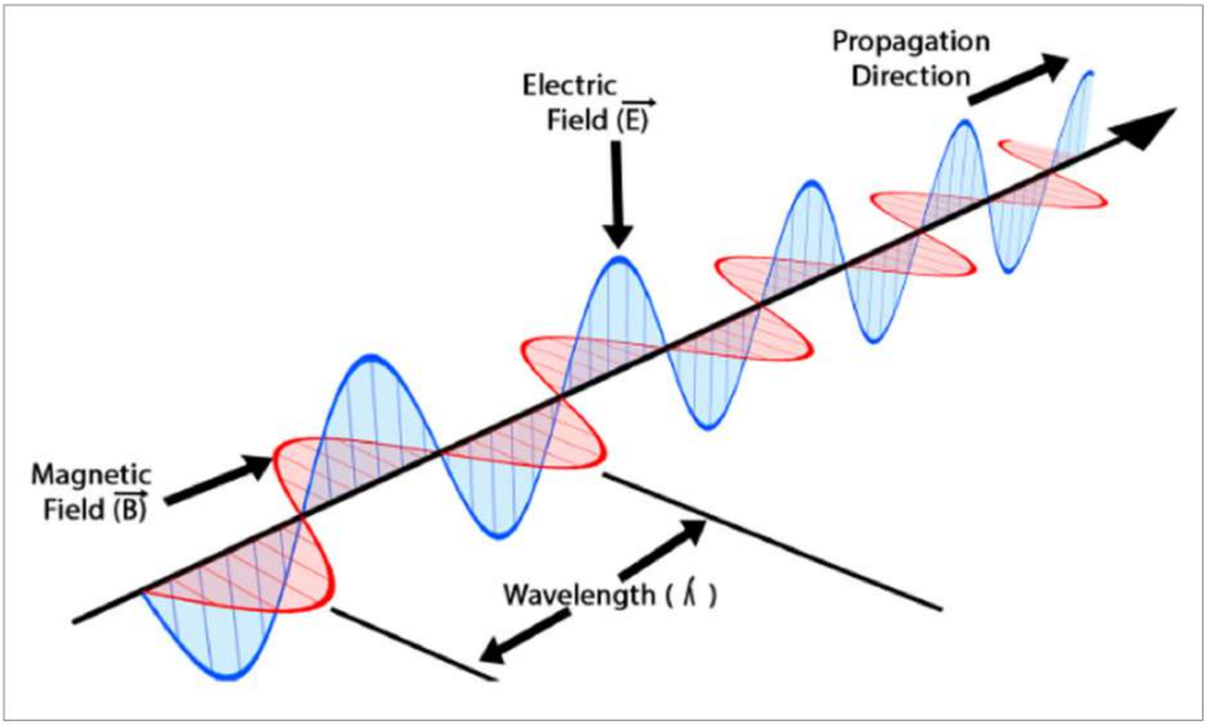



**Figure 3B: Maxwell's EM Transverse Wave**
Credit: https://physics.stackexchange.com.

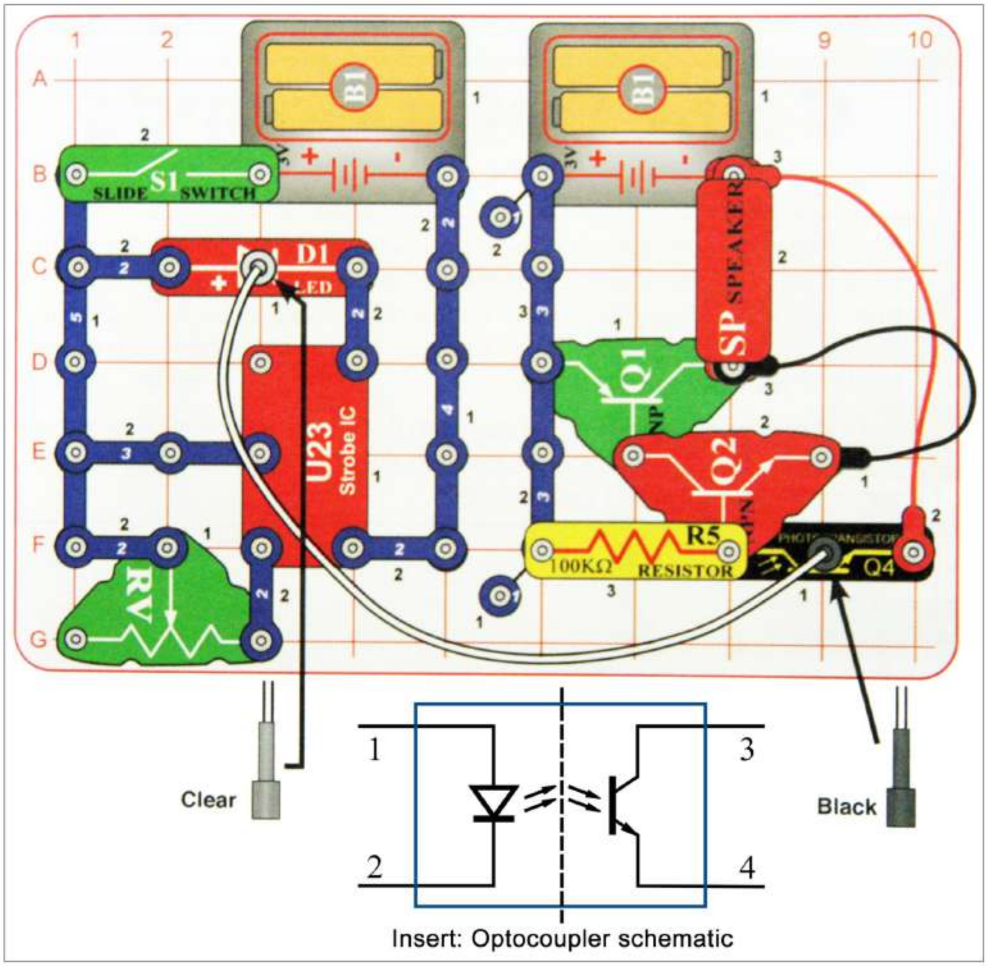
In 1905, Albert Einstein answered the age-old question about the dual wave-particle nature of light when he presented his theory explaining the photoelectric effect, which occurs when certain materials are exposed to light and they generate an electric current. Light, proven by Maxwell to be an EM wave—and therefore the entire EM spectrum—only exists because of a light speed (in a vacuum), zero rest mass, zero charge, discrete quantum bundle or packet, which he called "light quanta", later named "photon", in 1926. Individual photons have energy (moving orthogonal electric and magnetic fields) plus momentum proportional to its wavelength (frequency). The shorter the wavelength (higher the frequency) the more energy and momentum each photon carries, but it's a microscopic amount until the wavelength gets really short. Photons are emitted/absorbed by charged particles (electrons, positrons, protons and ions), or by sudden acceleration (or deceleration) of electrons, electron transitions in atoms, and thermonuclear reactions. They span a wide range of wavelengths (frequencies) and energies (temperatures/colours) creating an EM spectrum with manmade major divisions of: radio waves, microwaves, infrared (IR), visible light and ionizing radiation where the wavelength becomes shorter and shorter and the photon becomes more and more particle-like: ultraviolet, X-rays and gamma rays.

**The Optocoupler**

An optocoupler (optical coupler) or optoisolator (optical isolator) is an encapsulated solid-state device consisting of an input side usually using a LED, a dielectric barrier/channel plus an output side with a phototransistor or similar light sensitive device (Figure 4, insert). It electrically isolates/separates two different circuits but allows communications/control between them by using light. The dielectric is an extremely thin transparent material such as plastic or glass that focuses LED light on the phototransistor and also prevents any reflection back to the LED. A phototransistor is a special type of solid-state, bipolar junction transistor that operates via the photoelectric effect and has current gain. Most optical communications systems use variations of the optocoupler for converting an electrical signal to light transmitted at point A then back again when received at point B by separating the LED and phototransistor and using either a fibre optic cable or open air.

**Figure 4: Optical Communications: Fibre Optics**

Credit: Elenco Electronics.




Amateurs and other hobbyists typically use optical communications systems over open air for two-way voice, Morse code, data and even video. Serious experimenters have managed to send/receive signals between stations using high powered LEDs to distances over 200 kilometres between hilltops or mountain peaks! The higher up you are the farther the line-of-sight range to the optical horizon is plus the atmosphere is usually more stable and transparent than at ground level. But before buying/building then lugging equipment up hundreds of metres of hills or mountains, I'd rather try optical communications in the flat comfort of my home radio shack using an Elenco Snap Circuits kit specifically designed for hobbyists to see if this topic is interesting enough to pursue in more depth. Like LEGO Brick build kits, Snap Circuits build kits are very addictive and stimulate curiosity and creativity in minds of all ages across many fields of study, and you can even incorporate LEGO Brick builds into many Snap builds.

**Snap Circuits Light Kit**

To continue on and conduct the experiments, you'll need the Snap Circuits Light Kit or have the equivalent components in your parts box. There's a list of Snap Circuits kit suppliers provided in the References and Resources section of my part 1 article (see *TCA* May-June 2023). *Note: Because components are mounted horizontally, I'll use the supplied length of fibre optic cable for the visible light experiments.*

## Fibre Optics: Experiments 1 to 3

1. Build the circuit depicted in Figure 4 (Snap Circuits Light Kit, project 12). As you adjust variable resistor RV slowly from left to right, stopping in increments along the way, the voltage applied to the control pin of the "strobe" integrated circuit U23 varies; U23 is an encapsulated multivibrator (square wave) oscillator. The oscillator's audio output amplitude modulates the light output of red LED D1 (it will flicker at low voltages/low oscillations). Its light is transported via the fibre optic cable to a separate audio amplifier circuit whose audio tone and level are controlled by phototransistor (Q4) conversion of light to an electrical current.
2. The audio produced will be low in tone and level so replace it with LED D8. It's a special red, blue and green LED controlled by a programmed chip that rotates it's light output through various colours in a repeating sequence. Adjust RV again and compare the difference (if any) from the red LED.
3. Switch to white light LED D6 and repeat the experiment. There should be a now very noticeable difference. If you have other Snap Circuits kits, try green LED D2 or bicolour LED D10, which outputs yellow light when forward biased and orange-red (to my eyes) when reversed biased.

**Questions to Answer:** Why do different colours of light produce different audio tones as you adjust variable resistor RV? And why don't you see any light in the clear looking length of fibre optic cable? Remove it from the phototransistor and look at the open end when the circuit is active. *Caution: Only do this when using LEDs from this kit!*

## Fibre Optics: Experiment 4

4. Using white LED D6, adjust the audio level and tone using variable resistor RV then replace on/off switch S1 with press switch S2 to send Morse code by the on/off keying of oscillator U23.

Elenco also created a fibre optics communications kit (Figure 5) and training course (FO-30K). It's a separate transmitter and receiver (two kits required for two-way) that uses a fibre optic cable. But you can also use open air for line-of-sight experiments, bounce the LED light using mirrors, or see what happens when you pass the LED's output through various optical filters.

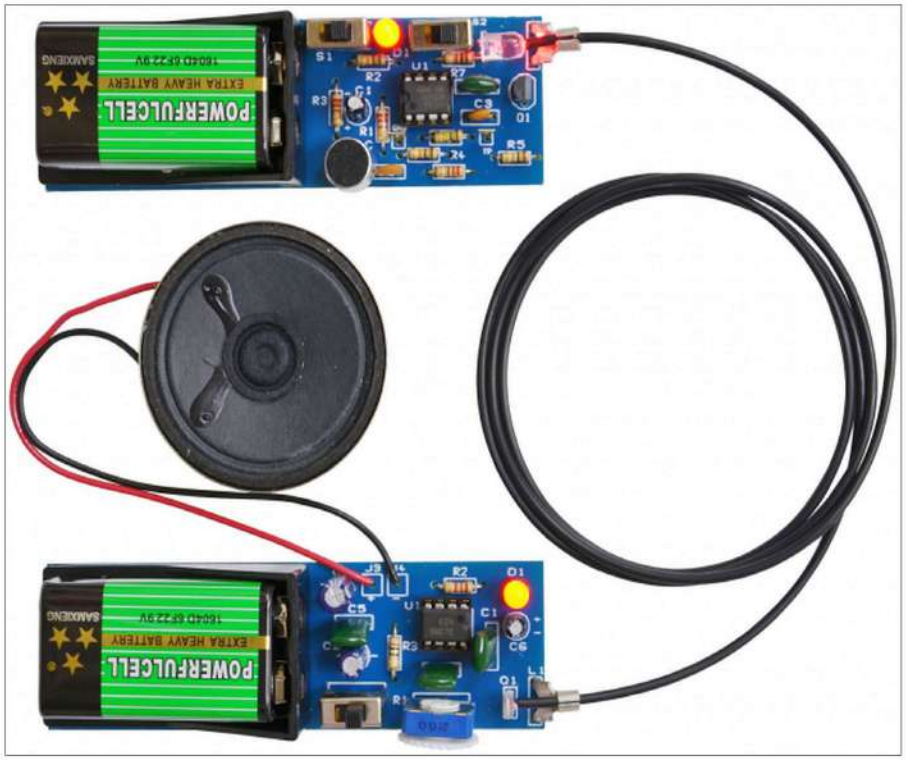


**Figure 5: Elenco Fibre Optics Kit (FO-30K)**
Credit: Elenco Electronics.

## Infrared: Experiments 5 to 8

There are five modern subdivisions of IR: near, short, middle, long and far. Near IR (meaning the nearest to visible light) is used by television/PVR IR remote controllers that transmit specific IR code sequences to various devices, but for this experiment we'll just detect the presence of any IR signal. Anything with a temperature emits IR energy (EM waves) that can be detected and measured by IR detectors. The James Webb Space Telescope (JWST) uses this simple fact to peer farther back in space-time, and consumer digital cameras can also image this light spectrum by using an IR optical filter (or be internally modified) for both terrestrial and astronomical photography.

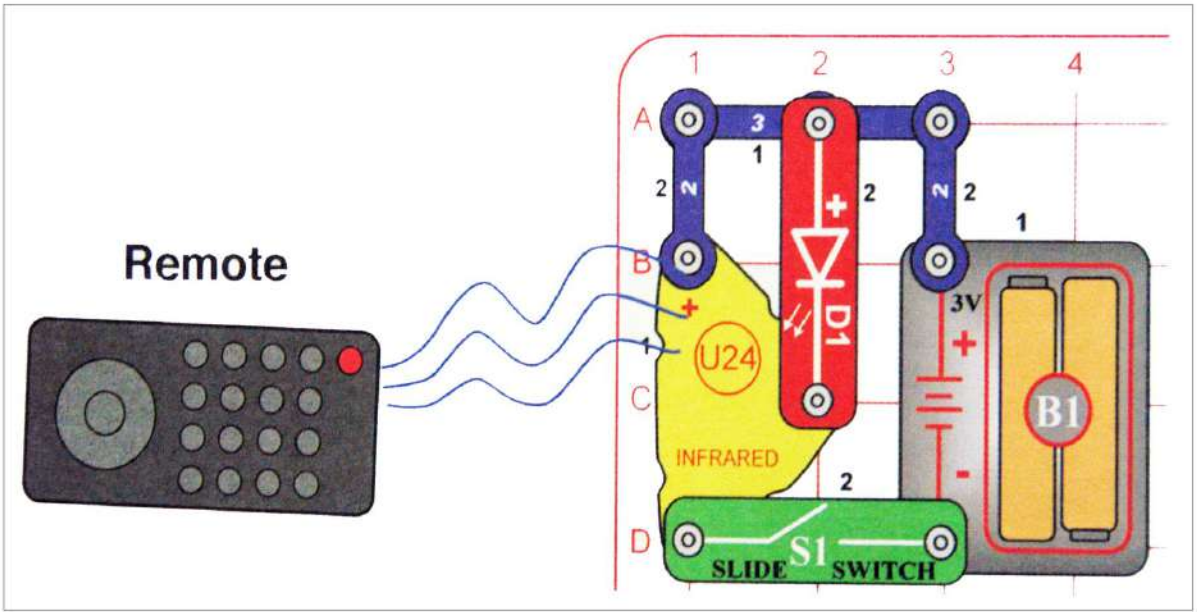



**Figure 6: Optical Communications: Infrared Detector**

Credit: Elenco Electronics.

5. Build the circuit depicted in Figure 6 (Snap Circuits Light Kit project 41). Now use any handy IR TV (or other) remote, point it at the infrared detector U24 and press any button on the remote;  red LED D1 should flash rapidly so long as you keep pressing the IR remote's button. Because white light sources also contain some IR, you may need to darken a brightly lit room.
6. Try sending slow Morse code across a room to the IR detector. You'll be sending a short series of flashing LED light for the "dot" and a longer series for the "dash". If you're quick with the finger press and release you can send just one flash for the dot.
7. Try reflecting your remote's IR light off of smooth walls, mirrors, paper and other flat objects to see if you can hit the IR detector and trigger the LED. Even make a game out of it (IR tag). You can also add sound to make it easier to confirm any "hits", and the Light Kit has several ways you can do this.
8. The Light Kit also comes with four optical filters: prismatic, red, blue and green. Put each type in front of your IR remote and see what affect, if any, they have on the IR beam.

## Visible Light: Experiments 9 and 10

9. Shine a white light source (an LED flashlight is perfect) through each optical filter and project the light produced on a flat white surface and observe the effect (if any) of each on white light.
10. If you have an air thermometer handy, in a darkened room shine the light produced by the red, green and blue filters on the thermometer to see if it can detect any increase or decrease in the ambient air temperature. It may not be sensitive enough but it doesn't hurt to try. A digital temperature sensor and microcontroller combination would definitely be able to show that the photons having different colours (wavelengths) also have different temperatures (energies).

**Question:** Why can't we detect IR (without electronic assistance) but other creatures naturally can. Hint: The answer is right before your eyes.

**My Final**

With Elenco's Snap Circuits Light Kit and/or additional resources, you can dive deeper into the principles and applications of optical communications. Experimenting with optical circuits and understanding the various properties of light opens the door to the fascinating world of optical technology that includes optical processing computers.—73

## References and Resources


Alexander Graham Bell https://tinyurl.com/mrxsx5cc

Charles Sumner Tainter https://tinyurl.com/bd337jx4

Electromagnetic Radiation https://tinyurl.com/3b8yh3h6

Elenco Electronics https://tinyurl.com/mtrkbbc5

Fibre Optics https://tinyurl.com/bdds2chd

James Webb Space Telescope https://tinyurl.com/mshwcrve

Multivibrator https://tinyurl.com/b56nfjsr

NASA: Inverse Square Law of Light (tutorial) https://tinyurl.com/bdeahxyr

Oliver Heaviside https://tinyurl.com/bdh3f2rs

Optical Communications for the Amateur https://tinyurl.com/mu94y6j7 https://tinyurl.com/43a6py3x and https://tinyurl.com/34vare48

Optical (Photonic) Computers https://tinyurl.com/yc29amyk

Optocoupler https://tinyurl.com/4xnmexnn

Photoelectric Effect https://tinyurl.com/4m827h29

Photophone https://tinyurl.com/yn26jj6u

Phototransistor https://tinyurl.com/24jy2mse

Snap Circuits Light Kit (manual) https://tinyurl.com/2b5m7zyd