



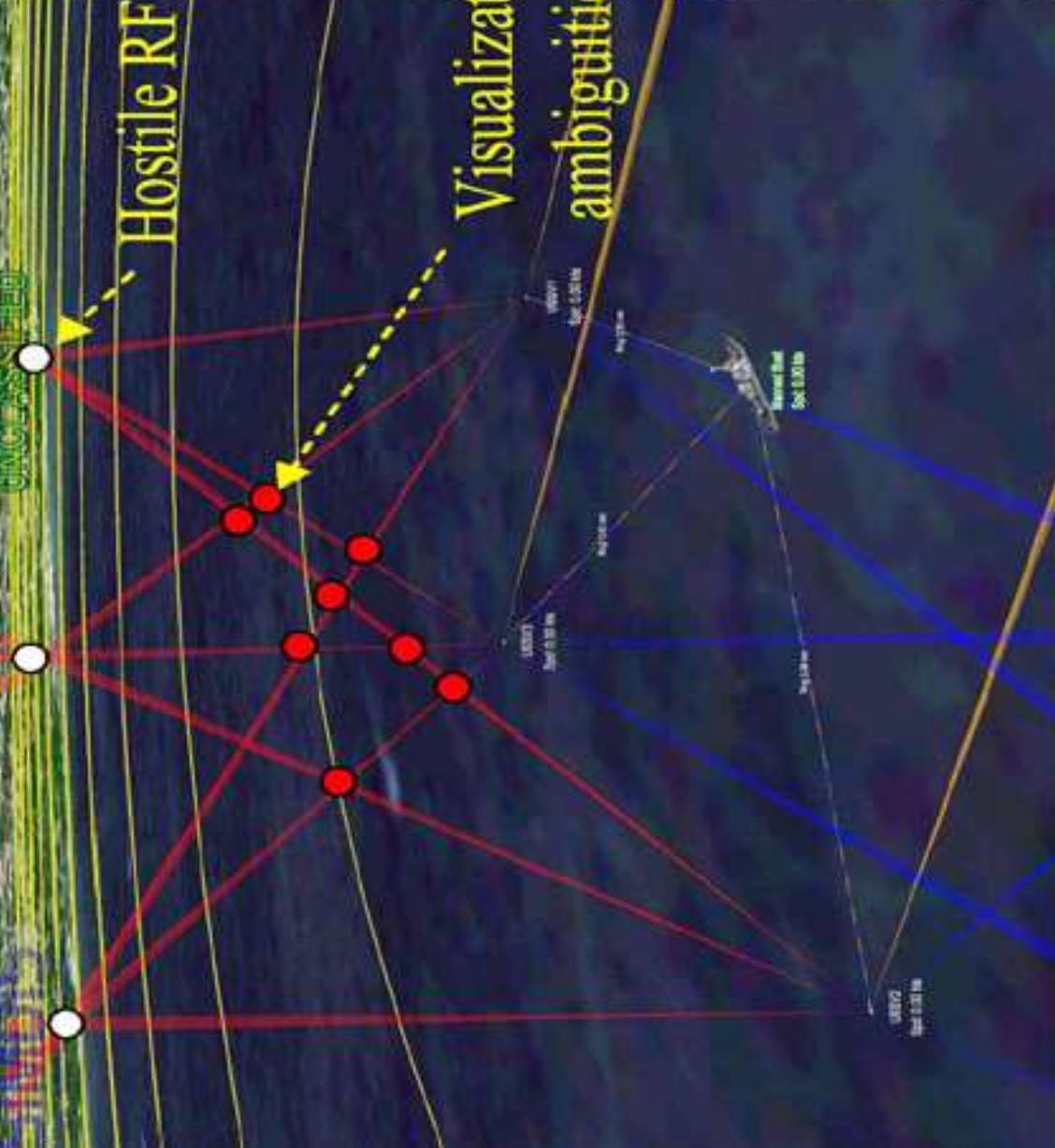
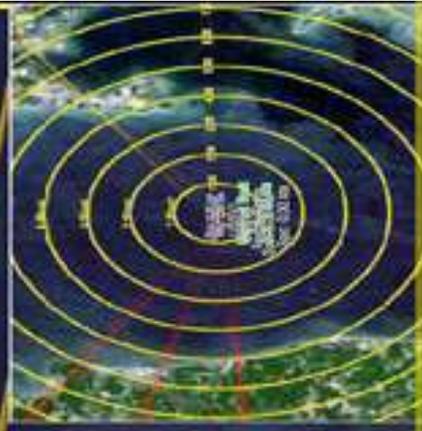
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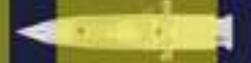
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Electronic Warfare

Pamela Higgs



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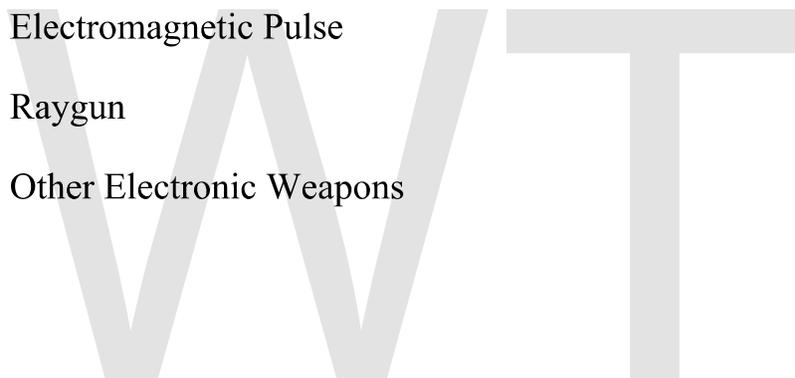
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WORLD TECHNOLOGIES

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Electronic Warfare

Electronic warfare (EW) refers to any action involving the use of the electromagnetic spectrum or directed energy to control the spectrum, attack an enemy, or impede enemy assaults via the spectrum. The purpose of electronic warfare is to deny the opponent the advantage of, and ensure friendly unimpeded access to, the EM spectrum. EW can be applied from air, sea, land, and space by manned and unmanned systems, and can target communication, radar, or other services. EW includes three major subdivisions: Electronic Attack (EA), Electronic Protection (EP), and Electronic warfare Support (ES).

Divisions



RAF Menwith Hill, a large ECHELON site in the United Kingdom, and part of the UK-USA Security Agreement.

Electronic support

Electronic Warfare Support (ES), is the subdivision of EW involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated electromagnetic (EM) energy for the purpose of immediate threat recognition, targeting, planning, and conduct of future operations.

An overlapping discipline, signals intelligence (SIGINT) is the related process of analyzing and identifying the intercepted frequencies (e.g. as a mobile phone or RADAR). SIGINT is broken into three categories: ELINT, COMINT, and FISINT.

Where these activities are under the control of an operational commander and being applied for the purpose of situational awareness, threat recognition, or EM targeting, they also serve the purpose of Electronic Warfare surveillance (ES).

Electronic attack

Electronic attack (EA) or electronic countermeasures (ECM) involves the use of the electromagnetic energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires.

EA operations can be detected by an adversary due to their active transmissions. Many modern EA techniques are considered to be highly classified. Examples of EA include communications jamming, IADS suppression, DE/LASER attack, expendable decoys (e.g., flares and chaff), and counter radio controlled improvised explosive device (C-RCIED) systems.



Inspecting an AN/ALQ-184 Electronic Attack Pod.

Electronic countermeasures (ECM) are a subsection of electronic warfare which includes any sort of electrical or electronic device designed to trick or deceive radar, sonar or other detection systems, like infrared (IR) or lasers. It may be used both offensively and defensively to deny targeting information to an enemy. The system may make many separate targets appear to the enemy, or make the real target appear to disappear or move about randomly. It is used effectively to protect aircraft from guided missiles. Most air forces use ECM to protect their aircraft from attack. It has also been deployed by military ships and recently on some advanced tanks to fool laser/IR guided missiles. It is frequently coupled with stealth advances so that the ECM systems have an

easier job. Offensive ECM often takes the form of jamming. Defensive ECM includes using blip enhancement and jamming of missile terminal homers.

History

One of the first examples of electronic countermeasures being applied in a combat situation took place during the Russo-Japanese war. On April 15, 1904, Russian wireless telegraphy stations installed in the Port Arthur fortress and on board Russian light cruisers successfully interrupted wireless communication between a group of Japanese battleships. The spark-gap transmitters in the Russian stations radioed a senseless noise while the Japanese were making attempts to coordinate their efforts in the bombing of a Russian naval base. Germany and Great Britain interfered with enemy communications along the western front during World War I while the Royal Navy tried to intercept German naval radio transmissions. There were also efforts at sending false radio signals, having shore stations send transmissions using ships' call signs, and jamming enemy radio signals. World War II ECM expanded to include jamming and spoofing radar and navigation signals. Cold War developments included missiles designed to home in on enemy radar transmitters.

Radar ECM

Basic radar ECM strategies are (1) radar interference, (2) target modifications, and (3) changing the electrical properties of air. Interference techniques include jamming and deception. Jamming is accomplished by a friendly platform transmitting signals on the radar frequency to produce a noise level sufficient to hide echos. The jammer's continuous transmissions will provide a clear direction to the enemy radar, but no range information. Deception may use a transponder to mimic the radar echo with a delay to indicate incorrect range. Transponders may alternatively increase return echo strength to make a small decoy appear to be a larger target. Target modifications include radar absorbing coatings and modifications of the surface shape to either "stealth" a high-value target or enhance reflections from a decoy. Dispersal of small aluminum strips called chaff is a common method of changing the electromagnetic properties of air to provide confusing radar echos.

Aircraft ECM



German Luftwaffe Tornado ECR.

ECM is practiced by nearly all modern military units—land, sea or air. Aircraft, however, are the primary weapons in the ECM battle because they can "see" a larger patch of earth than a sea or land-based unit. When employed effectively, ECM can keep aircraft from being tracked by search radars, or targeted by surface-to-air missiles or air-to-air missiles. On aircraft ECM can take the form of an attachable underwing pod or could be embedded in the airframe. Active Electronically Scanned Array (AESA) radars like those mounted on the F-22, MiG-35, Su-35BM or the F-35 can also act as an ECM device to track, locate and eventually jam enemy radar. Previous radar types were not capable of performing these activities due to:

- the inability of the antenna to use suboptimal frequencies
- the processing power needed
- the impossibility to practically intermix or segment antenna usages

Future Airborne Jammers

The Next Generation Jammer will be carried on the F-18G and F-35 fighters and use AESA technologies in side mounted pods to provide all around coverage with highly selective directional jamming.

DARPA's Precision Electronic Warfare (PREW) project aims to combine AESA with Synthetic aperture radar spread over multiple platforms for very tightly focused jamming.

The Air Force Research Laboratory is exploring the concept of a Cognitive Jammer to deal with Dynamic Spectrum Access technologies.

Examples of dedicated electronic countermeasures aircraft

- EC-130H Compass Call
- EA-6B Prowler equipped with ALQ-92 communications jammer, ALQ-100 multi-band track breaking system, and five ALQ-99 tactical jammer pods.
- EA-18G Growler
- Tornado ECR

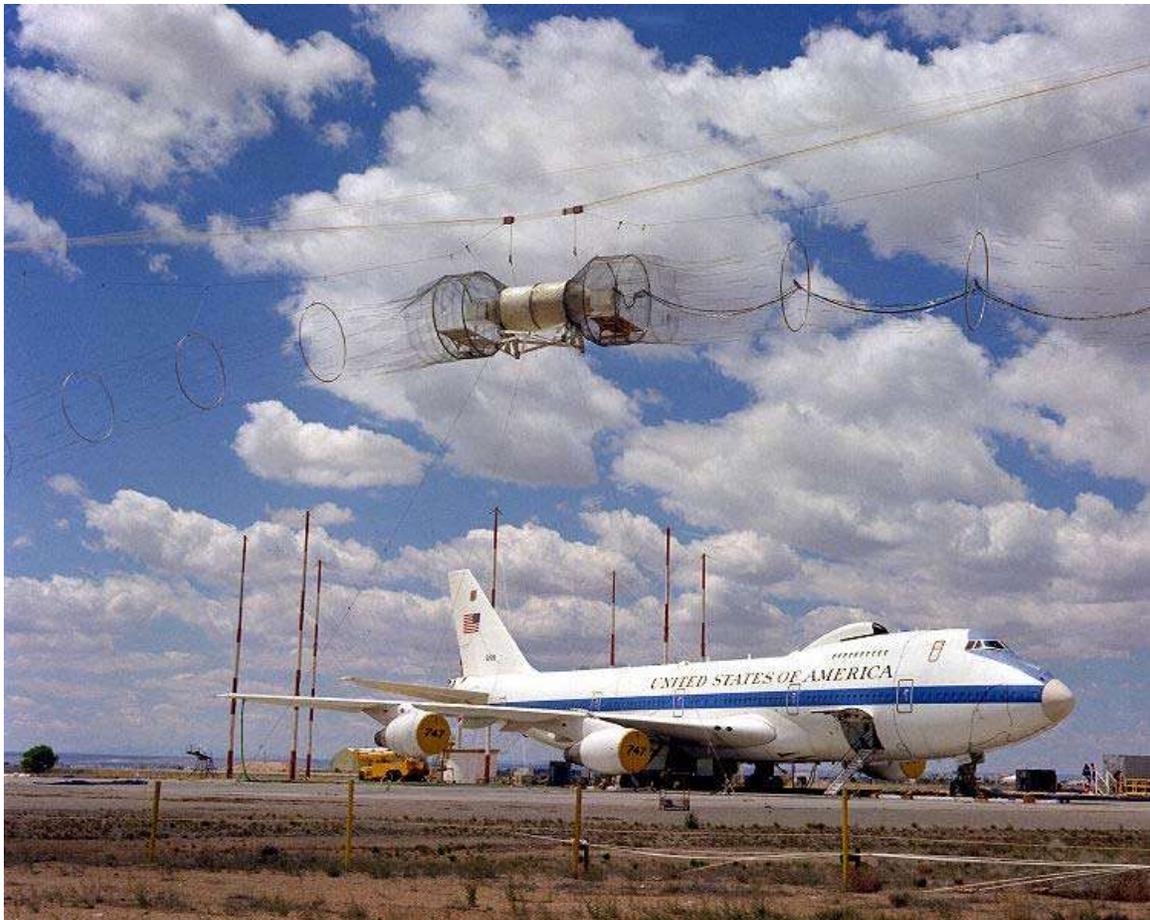
Heat and Sound Analogies

Infrared homing systems can be decoyed with flares. Sound detection and homing systems used for ships are also susceptible to countermeasures. United States warships use Masker and PRAIRIE (PRopellor AIR Ingestion and Emission) systems to create small air bubbles around a ship's hull and wake to reduce sound transmission. Surface ships tow noisemakers like the AN/SLQ-25 Nixie to decoy homing torpedoes. Submarines can deploy similar acoustic device countermeasures (or ADCs) from a 3-inch (75-mm) signal launching tube. United States ballistic missile submarines could deploy the Mark 70 MOSS (MOBILE Submarine Simulator) decoy from torpedo tubes to simulate a full size submarine.

Shipboard ECM

The ULQ-6 deception transmitter was one of the earlier shipboard ECM installations. The Raytheon SLQ-32 shipboard ECM package came in three versions providing warning, identification and bearing information about radar-guided cruise missiles. The SLQ-32 V3 included quick reaction electronic countermeasures for cruisers and large amphibious ships and auxiliaries in addition to the RBOC (Rapid Blooming Off-board Chaff) launchers found on most surface ships. The BLR-14 Submarine Acoustic Warfare System (or SAWS) provides an integrated receiver, processor, display, and countermeasures launch system for submarines.

Electronic protection



A right front view of a USAF Boeing E-4 advanced airborne command post (AABNCP) on the electromagnetic pulse (EMP) simulator (HAGII-C) for testing.

Electronic Protection (EP) (previously known as electronic protective measures (EPM) or electronic counter countermeasures (ECCM)) involves actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability. Jamming is not part of EP, it is an EA measure.

The use of flare rejection logic on an IR missile to counter an adversary's use of flares is EP. While defensive EA actions and EP both protect personnel, facilities, capabilities, and equipment, EP protects from the EFFECTS of EA (friendly and/or adversary). Other examples of EP include spread spectrum technologies, use of Joint Restricted Frequency List (JRFL), emissions control (EMCON), and low observability or "stealth".

Instance of Electronic Warfare

Battle of Latakia

The **Battle of Latakia** (Arabic: معركة اللاتقية; Hebrew: קרב לטקיה) was a small but revolutionary naval battle of the Yom Kippur War, fought on 7 October 1973, between Israel and Syria. It was the first naval battle in history to see combat between surface-to-surface missile-equipped missile boats and the use of electronic deception.

At the outset of hostilities, the Israeli Navy set out to destroy the naval capabilities of the Syrians, who were equipped with 3 modern Soviet Komar and Osa class missile boats. The Syrian missile-boats were equipped with Soviet manufactured P-15 Termit (NATO reporting name: SS-N-2 *Slyx*) missiles with twice the range of the Israeli Gabriel missiles. The 6 Israeli Navy Sa'ar 3-class missile boats charged towards the Syrian ships employing electronic countermeasures and chaff rockets to avoid being hit by Syrian missiles until they reached the range of their own missiles. The Israelis then fired Gabriel missiles and sunk their enemies. The Syrian Navy remained bottled up in its home ports for the rest of the war.

While the Battle of Latakia was the first naval battle in history between missile boats, it was not the first incident in which a missile boat sank another ship using missiles. That had happened when one Egyptian Soviet-built *Komar* class fast attack craft sank the British-built Israeli destroyer *Eilat* on 20 October 1967, shortly after the Six Day War, using two to four P-15 Termit (NATO reporting name: SS-N-2 *Slyx*) surface-to-surface missiles.

Battle of the Beams

The **Battle of the Beams** was a period early in the Second World War when bombers of the German Air Force (*Luftwaffe*) used a number of increasingly accurate systems of radio navigation for night bombing. British "scientific intelligence" at the Air Ministry fought back with a variety of increasingly effective means, involving jamming and

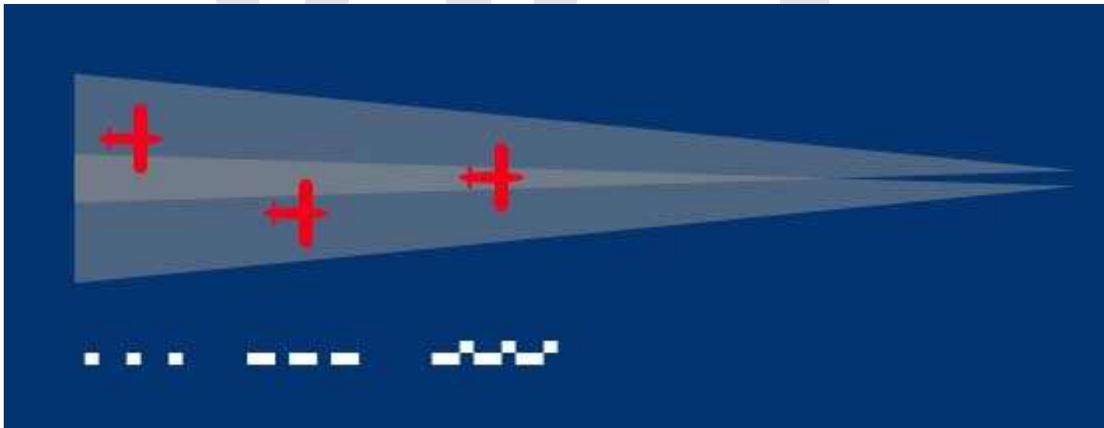
distortion of the radio waves. The period ended when the Germans moved their bomber forces to the East in May 1941, in preparation for the attack on the Soviet Union.

Background

Both the British and Germans based much of their pre-war bombing strategy on night bombing, in which the threats to the bombers from fighter interception and ground-based anti-aircraft systems were greatly reduced. However, the disadvantage of this strategy was the difficulty of finding a blacked-out target at night.

The Royal Air Force (RAF) thus invested very heavily in navigation training, equipping their aircraft with various equipment, including an astrodome, for taking a star fix and giving the navigator room to do calculations in a lit workspace. They put this system into use as soon as the war began and were initially happy with its success. In reality, the early bombing effort was a complete failure, with the majority of bombs landing miles away from their intended targets.

The Luftwaffe instead invested heavily in radio navigation systems to solve the same problem, notably neglecting any training in celestial navigation. They already had some experience with these sorts of systems due to their deployment of the Lorenz blind-landing aid at many airports, which also equipped most of their bombers to allow them to land at night or in bad weather.



The Lorenz beam and its two lobes of signal

The Lorenz system worked by feeding a special three-element antenna system with a modulated radio signal. The signal was fed to the centre dipole, which had a slightly longer reflector element on either side set slightly back. A special switch rapidly and alternately opened the mid point connection of each reflector in turn opening one for longer than the other. This sent a stream of dots to the left of the centreline and a stream of dashes to the right. Due to the directional characteristics of this arrangement, aircraft to the right of the runway centreline would receive a much stronger long signal ("dash") while those to the left would receive a stronger short signal ("dot"). The two signals

overlapped along a relatively narrow centreline, and since the received strengths of the dashes matched those of the dots such that a continuous *equisignal* was received. Lorenz could fly a plane down a straight line with relatively high accuracy, enough so that the aircraft could then find the runway visually in all but the worst conditions.

The Luftwaffe concentrated on developing a bombing direction system based on the Lorenz concept through the 1930s, as it made night navigation relatively easy by simply listening for signals on a radio set, and the necessary radios were already being installed on many aircraft. Lorenz directed an aircraft down a line, so two Lorenz-like systems with crossed beams could be used to fix a single spot. All that would be needed was a second Lorenz receiver.

Lorenz had a range of about 30 miles (48 km), enough for blind-landing but not good enough for bombing raids over the UK. This could be addressed by using more powerful transmitters and highly-sensitive receivers. In addition the beams of Lorenz were deliberately set wide enough that they could be easily picked up at some distance from the runway centreline, but this meant their accuracy at long ranges was fairly limited. This was not a problem for blind landing, where the distance covered by the fan-shaped beams decreased as the airplane approached the transmitters, but for use in the bombing role this would be reversed, and the system would have maximum inaccuracy over the target. To address this all that was needed was to make a much larger antenna array.

German systems

Knickebein

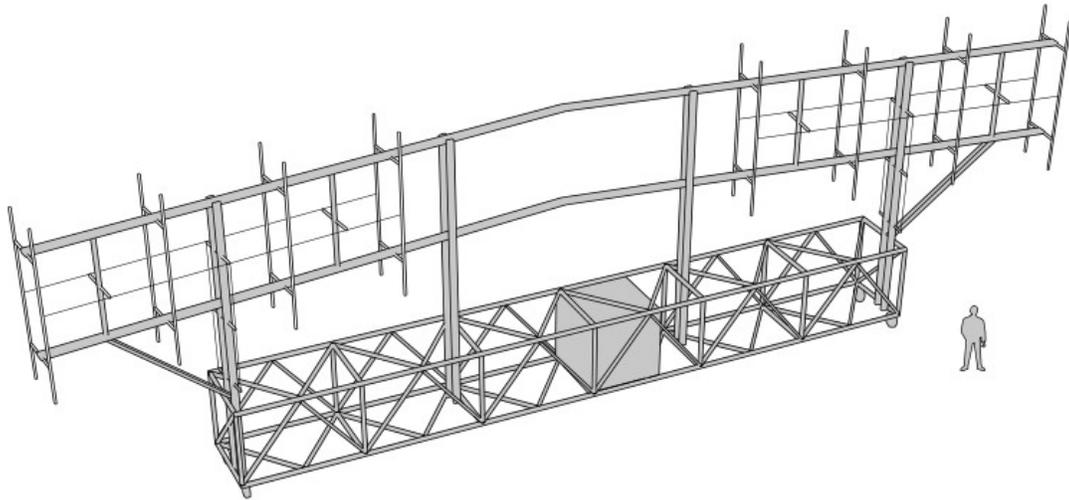


Map of Knickebein transmitters

For bombing use the modifications to Lorenz were fairly minor. Much larger antennas with considerably smaller beam angles were set up, and broadcast power was increased considerably. The aerials could be rotated to make the beams from two transmitters cross over the target. The bombers would fly into the beam of one and ride it until they started hearing the tones from the other (on the second receiver). When the steady "on course" sound was heard from the second beam, they dropped their bombs.

The first of these new Knickebein ("crooked leg") transmitters were set up in 1939 at Stollberg in northern Germany near the border with Denmark, at Kleve (Cleves) near the Dutch border, almost the most westerly point in Germany and at Lörrach near the border with France and Switzerland in south-western Germany. Following the fall of France in

June 1940, further transmitters were installed on the French coastline. Stations were also constructed in Norway and the Netherlands.



Later smaller Knickebein antenna

It was the shape of the aerials that gave the system its code name. Unlike the wide-pattern Lorenz, Knickebein required far more accuracy. This was achieved by using aerials with many more elements, but it retained the simple switching of two of the reflector elements to alter the beam directions very marginally.

The Knickebein receivers were disguised as a standard blind landing receiver system, consisting apparently of the EBL-1 and the EBL-2 blind landing receivers. The sensitivity of the receivers though had been considerably enhanced from the standard equipment in the hope that the British would not appreciate their purpose. Information overheard from captured aircrew revealed that the aircrew believed that the British would never find it (indicating that the equipment was on board the aircraft). In the event, the Royal Aircraft Establishment at Farnborough realised that the equipment was far more sensitive than it needed to be for a standard blind landing receiver. Knickebein was codenamed "Headache".

Knickebein was used in the early stages of the German night-bombing offensive, and proved to be fairly effective. However the tactics for using the system in a widespread bombing effort were not yet developed, so much of the early German night bombing offensive was limited to area bombing anyway.

The search for the beams

Efforts in Britain to stop the system took some time to get started. British intelligence at the Air Ministry, led by R V Jones, were aware of the system initially because a downed German bomber's Lorenz system was analysed and seen to be far too sensitive to be a

mere landing aid. Also secretly recorded transcripts from German POW pilots indicated this may have been a bomb aiming aid. Winston Churchill had also been given Ultra (intelligence from Enigma messages) mentioning 'bombing beams'.

When Jones mentioned the possibility of bombing beams to Churchill, Churchill put two and two together and ordered more investigation. However, many in the Air Ministry did not believe that the system was actually in use, and Frederick Lindemann, leading scientific adviser to the government, claimed that any such system would not be able to follow the curvature of the Earth, though T S Eckersley of the Marconi company had claimed it could.

Eckersley's claim was eventually demonstrated after Churchill ordered a flight to try to detect the beams. An Avro Anson was equipped with an American Hallicrafters S-27 amateur radio (then the only known receiver capable of receiving the 40 MHz signal) requisitioned from a shop in Lisle Street, London, operated by a member of the Y Service. The flight was nearly cancelled when Eckersley withdrew his claim that the beams would bend round the earth enough to be received. Only R V Jones could save the flight by pointing out that Churchill himself had ordered it and he would make sure that Churchill would get to know who cancelled it.

The crew were not told any specifics, and were simply ordered to search for radio signals around 40 MHz having Lorenz characteristics and, if they found any, to determine their bearing. The flight took off and eventually flew into the beam from Kleve. It subsequently located the cross beam from Stollberg (its origin was unknown prior to this flight). The radio operator and navigator were able to plot the path of the beams and discovered that they crossed right over the Rolls-Royce engine factory at Derby, at that time the only factory producing the Merlin engine. It was subsequently realised that the argument over whether the beams would bend round the earth or not was entirely academic as the transmitters were, more or less, in the line of sight to a bomber flying at high altitude.

Sceptics started regarding the system as proof that the German pilots were not as good as their own, who could do without such systems. It was Lindemann himself who proved this wrong, when his "photoflash" systems started returning photographs of the RAF bombing raids, showing that they were rarely, if ever, anywhere near their targets.

Countermeasure

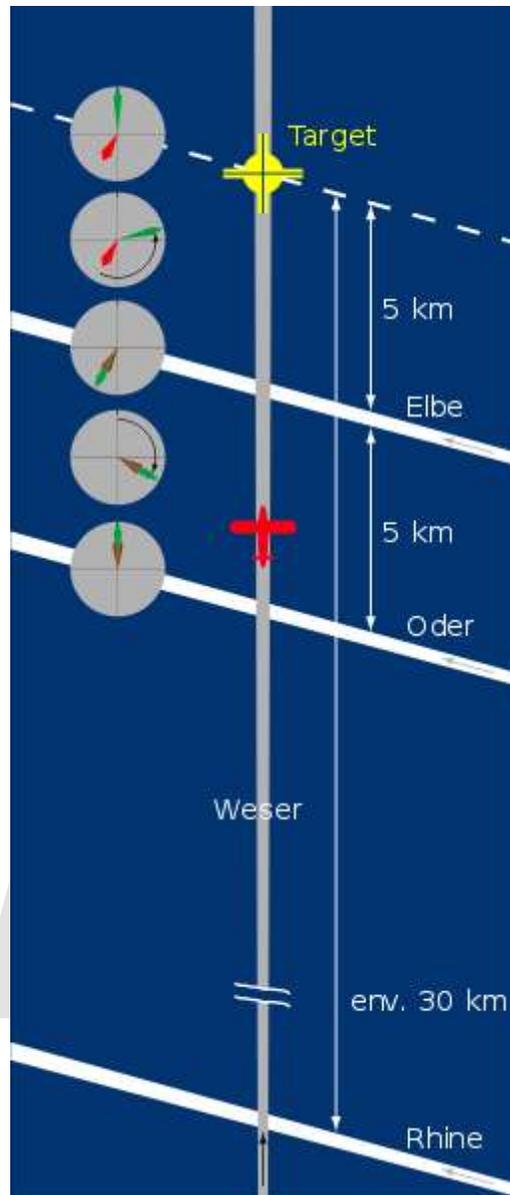
Efforts to block the Knickebein were brilliant in their simplicity (and aptly codenamed "Aspirin"). Initially, modified medical diathermy sets transmitted interference, but later, on nights where raids were expected, local radio transmitters broadcast a surplus "dot signal" at low power. The German predilection for turning on the beams long before the bombers reached the target area aided the British efforts. Ansons fitted with receivers would be flown around the country in an attempt to capture the beams' location, and a successful capture would then be reported to nearby broadcasters.

The low-power "dot signal" was initially broadcast essentially at random, so German navigators would hear two dots. This meant there were many equi-signal areas, and no easy way to distinguish them except by comparing with a known location. The British broadcasters were later modified to broadcast their dots at the same time the German transmitters would, making it impossible to tell which signal was which. In this case the navigators would receive the equi-signal over a wide area, and navigation along the bomblines became impossible, with the aircraft drifting into the "dash area" and no way to correct for it.

Thus the beam was "bent" away from the target. Eventually, the beams could be bent by a controlled amount which enabled the British to fool the Germans into dropping their bombs where they wanted them. A side effect was that as the German crews had been trained to navigate solely by the beams, many crews failed to find either the true equi-signal or Germany again. Some bombers even landed at RAF bases, believing they were back in Germany.

X-Gerät

As good as Knickebein was, it was never invented to be used in the long-range role. Efforts had been underway for some time to produce a much more accurate version of the same basic concept, which was eventually delivered as X-Gerät (translated "X-Apparatus").



Principle of the German help system X-Gerät for night bombing

X-Gerät used a series of beams to locate the target, each beam named after a river. The main beam, *Weser*, was similar in concept to the one used in Knickebein, but operated at a much higher frequency. Due to the nature of radio propagation, this allowed its two beams to be pointed much more accurately than Knickebein from a similarly sized antenna; the equi-signal area was only about 100 yards (91 m) wide at a distance of 200 miles (320 km) from the antenna. The beams were so narrow bombers could not find them on their own, so a low-power wide-beam version of Knickebein was set up at the same station to act as a guide. The main *Weser* broadcast antenna was set up just to the west of Cherbourg.

The "cross" signal in X-Gerät used a series of three very narrow single beams, *Rhine*, *Oder* and *Elbe*. About 30 kilometres (18.6 mi) from the target the radio operator would hear a brief signal from Rhine, and set up his equipment. This consisted of a special stopclock with two hands. When the Oder signal was received the clock automatically started and the two hands started to sweep up from zero. When the signal from Elbe was received the clock reversed, at which point one hand would stop and the other would start moving back towards zero. Oder and Elbe were aimed to be roughly 5 to 10 kilometres (3.1 to 6.2 mi) from the bomb release point along the line of *Weser* (the exact distance depending on the distance from the transmitter), meaning that the clock accurately measured the time to travel between the first two beams along the flight path. Since the time taken to travel that distance should be the same as the time needed to travel the last 5 kilometres (3.1 mi) from Elbe to the target, when the moving hand reached zero the bombs were automatically released. To be exact, the Elbe signal was adjusted to correct for the distance the bombs would travel between release and impact.

Since X-Gerät operated on a much higher frequency than Knickebein (around 60 MHz) it required new radio equipment to be used. There were not nearly enough sets to go around, so instead the experimental unit KGr 100 (*Kampfgruppe* 100) was given the task of using their sets in order to guide other planes to the target. To do this, KGr 100 planes would attack as a small group first, dropping flares which other planes would then see and bomb visually. This is the first use of the *pathfinder* concept that the RAF would later perfect to great effect against the Germans only a few years later.

X-Gerät was used to great effect in a series of raids known to the Germans as *Moonlight Sonata*, against Coventry, Wolverhampton and Birmingham. In the raid on Birmingham only KGr 100 was used, and British post-raid analysis showed that the vast majority of the bombs dropped were placed within 100 yards (91 m) of the midline of the Weser beam, spread along it a few hundred yards. This was the sort of accuracy that even daytime bombing could rarely achieve. A similar raid on Coventry with full support from other units dropping on their flares nearly destroyed the city centre.

Countermeasure

X-Gerät proved more difficult to stop than Knickebein. Initial defences against the system were deployed in a similar fashion to Knickebein in an attempt to disrupt the Coventry raid, but proved to be a total failure. Although Jones had correctly guessed the beam layout (and acknowledges it was only a guess), the modulation frequency had been measured incorrectly as 1500 Hz, but was in fact 2000 Hz. At the time it was believed that this would not make any difference, as the tones were close enough that an operator would have a hard time distinguishing them in a noisy aircraft.

The mystery was eventually revealed after an X-Gerät-equipped Heinkel He 111 crashed on 6 November 1940 on the English coast at Chesil Beach. Although the plane sank during the recovery operation, the waterlogged X-Gerät equipment was recovered. On examination, it was learned that a new instrument was being used that automatically decoded the dots and dashes and displayed a pointer in the cockpit in front of the pilot.

This device was fitted with a very sharp filter which was sensitive only at 2000 Hz, and not the early British 1500 Hz counter-signals. While the jammers were modified accordingly, this came too late for the raid on Coventry on 14 November, but the modified jammers were able to successfully disrupt a raid on Birmingham on 19 November.

X-Gerät was eventually defeated in another manner, by way of a "false Elbe" which was set up to cross the Weser guide beam at a mere 1 kilometre (0.6 mi) after the preceding Oder beam — much earlier than the expected 5 kilometres (3.1 mi). Since the final stages of the release were automatic, the clock would reverse prematurely and drop the bombs kilometres short of the target. Setting up this false beam proved very problematic as the Germans, learning from their mistakes with Knickebein, didn't switch the X-Gerät beams on until as late as possible, making it much more difficult to arrange the "false Elbe" in time.

Y-Gerät

As the British slowly gained the upper hand in the Battle of the Beams, they started considering what the next German system would entail. Since Germany's current approaches had been rendered useless, an entirely new system would have to be developed. It was thought that if the British could defeat this new system very quickly, the Germans would abandon their attempts entirely.

British monitors soon started receiving intelligence intercepts referring to a new device known as Y-Gerät, which was also sometimes referred to as Wotan. R V Jones had already concluded the Germans used code names which were too descriptive. He asked a specialist in German language and literature at Bletchley Park about the word Wotan. The specialist realised Wotan, the name of a one-eyed god, might be a single beam navigation system. Jones agreed and knew it would have to be based on a distance-measurement system. He also concluded it might well work on the system described by a German well-wisher in Norway, who had passed a large amount of information in what is now known as the Oslo Report.

Y-Gerät used a single narrow beam pointed over the target, broadcasting a modulated radio signal. The system used a new piece of equipment that received the signal from the beam and immediately re-broadcast it back to the ground station. The ground station listened for the return signal and compared its phase to the transmitted signal. This is an accurate way of measuring the transit time of the signal, and hence the distance to the aircraft. Coupled with the direction of the beam (adjusted for maximum return signal), the bomber's position could be established with considerable accuracy. The bombers did not have to track the beam, instead the ground controllers could calculate it and then gave radio instructions to the pilot to correct the flight path.

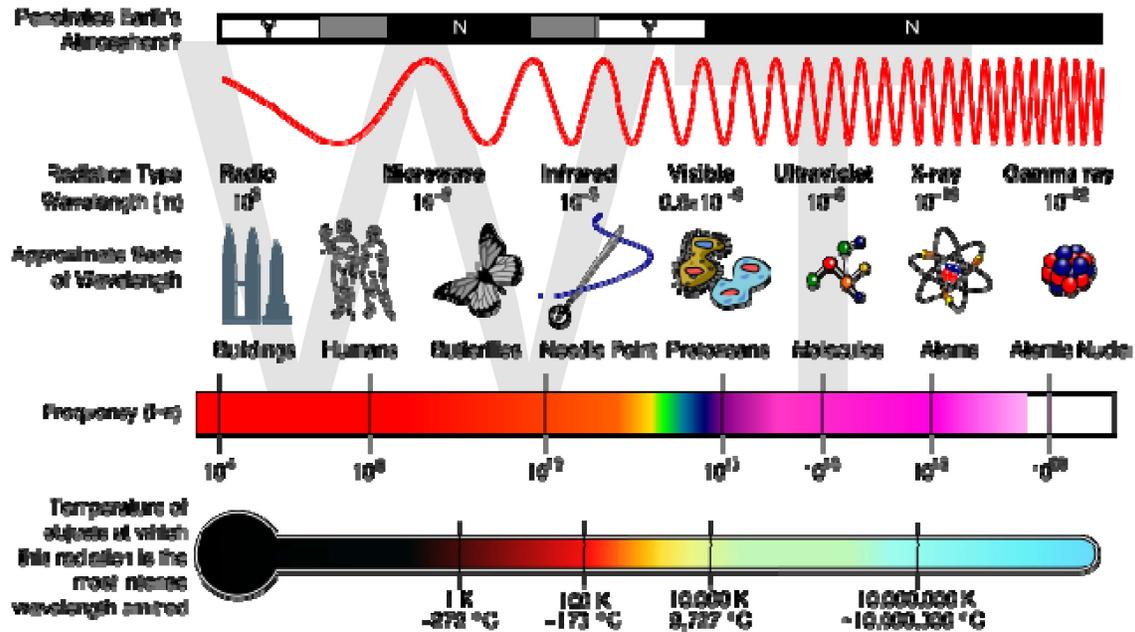


Alexandra Palace

The British were ready for this system even before it was used. By chance, the Germans had chosen the operating frequency of the Wotan system very badly; it operated on 45 MHz, which just happened to be the frequency of the powerful-but-dormant BBC television transmitter at Alexandra Palace. All Jones had to do was arrange for the return signal to be received from the aircraft and then sent to Alexandra Palace for re-transmission. The combination of the two signals modified the phase shift — and the apparent transit delay. Initially, the signal was re-transmitted at a low power, not powerful enough for the Germans to realise what was happening, but enough to spoil the accuracy of the system. Over subsequent nights, the transmitter power was gradually increased.

As Wotan's use went on, the aircrew accused the ground station of sending bad signals and the ground station accused the aircraft of having loose connections. The whole scheme appealed to Jones as he was a natural practical joker, and remarked that he was able to play one of the largest practical jokes with virtually any national resource that he required. The gradually increasing power conditioned the Germans such they did not realise that anyone was interfering with the system, but believed that it suffered several inherent defects. Eventually, as the power was increased enough, the whole Wotan system started to ring with all the feedback.

Electromagnetic Spectrum



Although some radiations are marked as "N" for "no" in the diagram, some waves do in fact penetrate the atmosphere, although extremely minimally compared to the other radiations.

The **electromagnetic spectrum** is the range of all possible frequencies of electromagnetic radiation. The "electromagnetic spectrum" of an object is the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object.

The electromagnetic spectrum extends from low frequencies used for modern radio to gamma radiation at the short-wavelength end, covering wavelengths from thousands of

kilometers down to a fraction of the size of an atom. The long wavelength limit is the size of the universe itself, while it is thought that the short wavelength limit is in the vicinity of the Planck length, although in principle the spectrum is infinite and continuous.

CLASS	FREQUENCY	WAVELENGTH	ENERGY
Y	300 EHz	1 pm	1.24 MeV
HX	30 EHz	10 pm	124 keV
SX	3 EHz	100 pm	12.4 keV
EUV	300 PHz	1 nm	1.24 keV
NUV	30 PHz	10 nm	124 eV
Visible light	3 PHz	100 nm	12.4 eV
NIR	300 THz	1 μm	1.24 eV
MIR	30 THz	10 μm	124 meV
FIR	3 THz	100 μm	12.4 meV
EHF	300 GHz	1 mm	1.24 meV
SHF	30 GHz	1 cm	124 μeV
UHF	3 GHz	1 dm	12.4 μeV
VHF	300 MHz	1 m	1.24 μeV
HF	30 MHz	10 m	124 neV
MF	3 MHz	100 m	12.4 neV
LF	300 kHz	1 km	1.24 neV
VLF	30 kHz	10 km	124 peV
VF/ULF	3 kHz	100 km	12.4 peV
SLF	300 Hz	1 Mm	1.24 peV
ELF	30 Hz	10 Mm	124 feV
	3 Hz	100 Mm	12.4 feV

Legend

γ= Gamma rays

HX= Hard X-rays

SX= Soft X-rays

EUV= Extreme ultraviolet EHF= Extremely high freq. VLF= Very low freq.

NUV= Near ultraviolet SHF= Super high freq. VF/ULF= Voice freq.

Visible light UHF= Ultra high freq. SLF= Super low freq.

NIR= Near Infrared VHF= Very high freq. ELF= Extremely low freq.

Freq=Frequency

Range of the spectrum

EM waves are typically described by any of the following three physical properties: the frequency f , wavelength λ , or photon energy E . Frequencies range from 2.4×10^{23} Hz (1 GeV gamma rays) down to the local plasma frequency of the ionized interstellar medium

(~1 kHz). Wavelength is inversely proportional to the wave frequency, so gamma rays have very short wavelengths that are fractions of the size of atoms, whereas wavelengths can be as long as the universe. Photon energy is directly proportional to the wave frequency, so gamma rays have the highest energy (around a billion electron volts) and radio waves have very low energy (around femto electron volts). These relations are illustrated by the following equations:

$$f = \frac{c}{\lambda}, \quad \text{or} \quad f = \frac{E}{h}, \quad \text{or} \quad E = \frac{hc}{\lambda},$$

where:

- $c = 299,792,458$ m/s is the speed of light in vacuum and
- $h = 6.62606896(33) \times 10^{-34}$ J s = $4.13566733(10) \times 10^{-15}$ eV s is Planck's constant.

Whenever electromagnetic waves exist in a medium with matter, their wavelength is decreased. Wavelengths of electromagnetic radiation, no matter what medium they are traveling through, are usually quoted in terms of the *vacuum wavelength*, although this is not always explicitly stated.

Generally, EM radiation is classified by wavelength into radio wave, microwave, infrared, the visible region we perceive as light, ultraviolet, X-rays and gamma rays. The behavior of EM radiation depends on its wavelength. When EM radiation interacts with single atoms and molecules, its behavior also depends on the amount of energy per quantum (photon) it carries.

Spectroscopy can detect a much wider region of the EM spectrum than the visible range of 400 nm to 700 nm. A common laboratory spectroscope can detect wavelengths from 2 nm to 2500 nm. Detailed information about the physical properties of objects, gases, or even stars can be obtained from this type of device. Spectroscopes are widely used in astrophysics. For example, many hydrogen atoms emit a radio wave photon which has a wavelength of 21.12 cm. Also, frequencies of 30 Hz and below can be produced by and are important in the study of certain stellar nebulae and frequencies as high as 2.9×10^{27} Hz have been detected from astrophysical sources.

Rationale

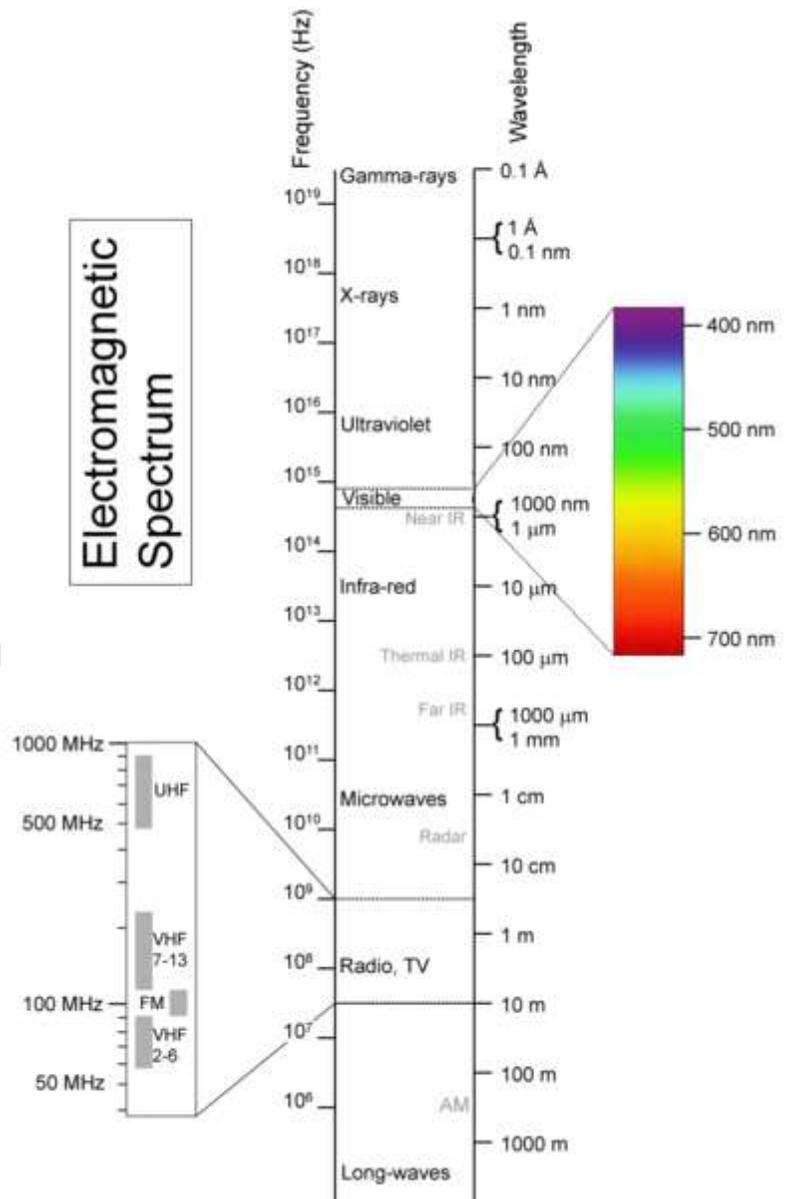
Electromagnetic radiation interacts with matter in different ways in different parts of the spectrum. The types of interaction can be so different that it seems to be justified to refer to different types of radiation. At the same time, there is a continuum containing all these "different kinds" of electromagnetic radiation. Thus we refer to a spectrum, but divide it up based on the different interactions with matter.

Region of the spectrum

Main interactions with matter

Radio	Collective oscillation of charge carriers in bulk material (plasma oscillation). An example would be the oscillation of the electrons in an antenna.
Microwave through far infrared	Plasma oscillation, molecular rotation
Near infrared	Molecular vibration, plasma oscillation (in metals only)
Visible	Molecular electron excitation (including pigment molecules found in the human retina), plasma oscillations (in metals only)
Ultraviolet	Excitation of molecular and atomic valence electrons, including ejection of the electrons (photoelectric effect)
X-rays	Excitation and ejection of core atomic electrons, Compton scattering (for low atomic numbers)
Gamma rays	Energetic ejection of core electrons in heavy elements, Compton scattering (for all atomic numbers), excitation of atomic nuclei, including dissociation of nuclei
High energy gamma rays	Creation of particle-antiparticle pairs. At very high energies a single photon can create a shower of high energy particles and antiparticles upon interaction with matter.

Types of radiation



The electromagnetic spectrum

While the classification scheme is generally accurate, in reality there is often some overlap between neighboring types of electromagnetic energy. For example, SLF radio waves at 60 Hz may be received and studied by astronomers, or may be ducted along wires as electric power, although the latter is, strictly speaking, not electromagnetic radiation at all. The distinction between X and gamma rays is based on sources: gamma rays are the photons generated from nuclear decay or other nuclear and subnuclear/particle process, whereas X-rays are generated by electronic transitions involving highly energetic inner atomic electrons. Generally, nuclear transitions are much more energetic than electronic transitions, so usually, gamma-rays are more energetic than X-rays, but exceptions exist. By analogy to electronic transitions, muonic atom transitions are also said to produce X-rays, even though their energy may exceed

6 megaelectronvolts (0.96 pJ), whereas there are many (77 known to be less than 10 keV (1.6 fJ)) low-energy nuclear transitions (e.g. the 7.6 eV (1.22 aJ) nuclear transition of thorium-229), and despite being one million-fold less energetic than some muonic X-rays, the emitted photons are still called gamma rays due to their nuclear origin.

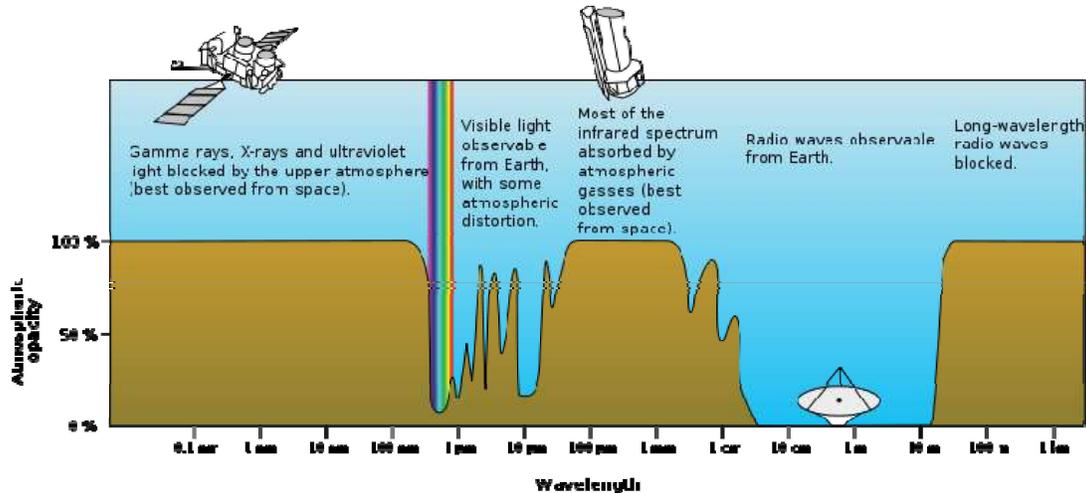
Also, the region of the spectrum of the particular electromagnetic radiation is reference-frame dependent (on account of the Doppler shift for light) so EM radiation which one observer would say is in one region of the spectrum could appear to an observer moving at a substantial fraction of the speed of light with respect to the first to be in another part of the spectrum. For example, consider the cosmic microwave background. It was produced, when matter and radiation decoupled, by the de-excitation of hydrogen atoms to the ground state. These photons were from Lyman series transitions, putting them in the ultraviolet (UV) part of the electromagnetic spectrum. Now this radiation has undergone enough cosmological red shift to put it into the microwave region of the spectrum for observers moving slowly (compared to the speed of light) with respect to the cosmos. However, for particles moving near the speed of light, this radiation will be blue-shifted in their rest frame. The highest energy cosmic ray protons are moving such that, in their rest frame, this radiation is blueshifted to high energy gamma rays which interact with the proton to produce bound quark-antiquark pairs (pions). This is the source of the GZK limit.

Radio frequency

Radio waves generally are utilized by antennas of appropriate size (according to the principle of resonance), with wavelengths ranging from hundreds of meters to about one millimeter. They are used for transmission of data, via modulation. Television, mobile phones, wireless networking and amateur radio all use radio waves. The use of the radio spectrum is regulated by many governments through frequency allocation.

Radio waves can be made to carry information by varying a combination of the amplitude, frequency and phase of the wave within a frequency band. When EM radiation impinges upon a conductor, it couples to the conductor, travels along it, and induces an electric current on the surface of that conductor by exciting the electrons of the conducting material. This effect (the skin effect) is used in antennas. **EM** radiation may also cause certain molecules to absorb energy and thus to heat up, causing thermal effects and sometimes burns. This is exploited in microwave ovens.

Microwaves



Plot of Earth's atmospheric transmittance (or opacity) to various wavelengths of electromagnetic radiation.

The super high frequency (SHF) and extremely high frequency (EHF) of microwaves come next up the frequency scale. Microwaves are waves which are typically short enough to employ tubular metal waveguides of reasonable diameter. Microwave energy is produced with klystron and magnetron tubes, and with solid state diodes such as Gunn and IMPATT devices. Microwaves are absorbed by molecules that have a dipole moment in liquids. In a microwave oven, this effect is used to heat food. Low-intensity microwave radiation is used in Wi-Fi, although this is at intensity levels unable to cause thermal heating.

Volumetric heating, as used by microwaves, transfers energy through the material electromagnetically, not as a thermal heat flux. The benefit of this is a more uniform heating and reduced heating time; microwaves can heat material in less than 1% of the time of conventional heating methods.

When active, the average microwave oven is powerful enough to cause interference at close range with poorly shielded electromagnetic fields such as those found in mobile medical devices and cheap consumer electronics.

Terahertz radiation

Terahertz radiation is a region of the spectrum between far infrared and microwaves. Until recently, the range was rarely studied and few sources existed for microwave energy at the high end of the band (sub-millimetre waves or so-called terahertz waves), but applications such as imaging and communications are now appearing. Scientists are also looking to apply terahertz technology in the armed forces, where high frequency waves might be directed at enemy troops to incapacitate their electronic equipment.

Infrared radiation

The infrared part of the electromagnetic spectrum covers the range from roughly 300 GHz (1 mm) to 400 THz (750 nm). It can be divided into three parts:

- **Far-infrared**, from 300 GHz (1 mm) to 30 THz (10 μm). The lower part of this range may also be called microwaves. This radiation is typically absorbed by so-called rotational modes in gas-phase molecules, by molecular motions in liquids, and by phonons in solids. The water in the Earth's atmosphere absorbs so strongly in this range that it renders the atmosphere effectively opaque. However, there are certain wavelength ranges ("windows") within the opaque range which allow partial transmission, and can be used for astronomy. The wavelength range from approximately 200 μm up to a few mm is often referred to as "sub-millimetre" in astronomy, reserving far infrared for wavelengths below 200 μm .
- **Mid-infrared**, from 30 to 120 THz (10 to 2.5 μm). Hot objects (black-body radiators) can radiate strongly in this range. It is absorbed by molecular vibrations, where the different atoms in a molecule vibrate around their equilibrium positions. This range is sometimes called the *fingerprint region* since the mid-infrared absorption spectrum of a compound is very specific for that compound.
- **Near-infrared**, from 120 to 400 THz (2,500 to 750 nm). Physical processes that are relevant for this range are similar to those for visible light.

Visible radiation (light)

Above infrared in frequency comes visible light. This is the range in which the sun and stars similar to it emit most of their radiation. It is probably not a coincidence that the human eye is sensitive to the wavelengths that the sun emits most strongly. Visible light (and near-infrared light) is typically absorbed and emitted by electrons in molecules and atoms that move from one energy level to another. The light we see with our eyes is really a very small portion of the electromagnetic spectrum. A rainbow shows the optical (visible) part of the electromagnetic spectrum; infrared would be located just beyond the red side of the rainbow with ultraviolet appearing just beyond the violet end.

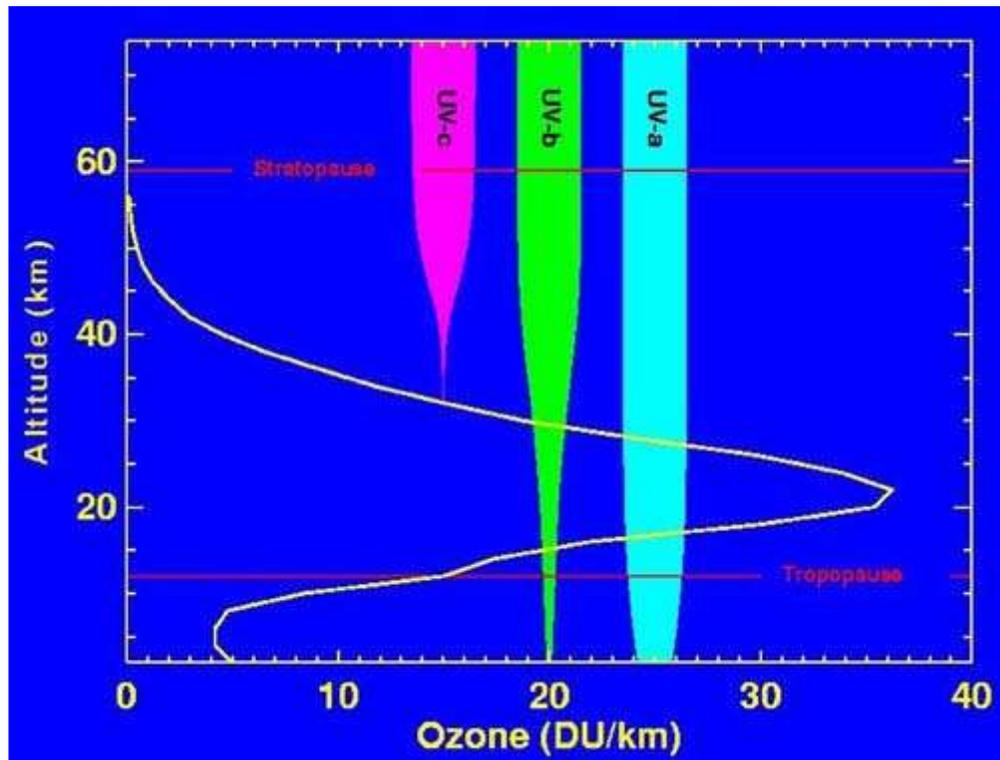
Electromagnetic radiation with a wavelength between 380 nm and 760 nm (790–400 terahertz) is detected by the human eye and perceived as visible light. Other wavelengths, especially near infrared (longer than 760 nm) and ultraviolet (shorter than 380 nm) are also sometimes referred to as light, especially when the visibility to humans is not relevant.

If radiation having a frequency in the visible region of the EM spectrum reflects off an object, say, a bowl of fruit, and then strikes our eyes, this results in our visual perception of the scene. Our brain's visual system processes the multitude of reflected frequencies into different shades and hues, and through this not-entirely-understood psychophysical phenomenon, most people perceive a bowl of fruit.

At most wavelengths, however, the information carried by electromagnetic radiation is not directly detected by human senses. Natural sources produce EM radiation across the

spectrum, and our technology can also manipulate a broad range of wavelengths. Optical fiber transmits light which, although not suitable for direct viewing, can carry data that can be translated into sound or an image. The coding used in such data is similar to that used with radio waves.

Ultraviolet light



The amount of penetration of UV relative to altitude in Earth's ozone

Next in frequency comes ultraviolet (UV). This is radiation whose wavelength is shorter than the violet end of the visible spectrum, and longer than that of an X-ray.

Being very energetic, UV can break chemical bonds, making molecules unusually reactive or ionizing them, in general changing their mutual behavior. Sunburn, for example, is caused by the disruptive effects of UV radiation on skin cells, which is the main cause of skin cancer, if the radiation irreparably damages the complex DNA molecules in the cells (UV radiation is a proven mutagen). The Sun emits a large amount of UV radiation, which could quickly turn Earth into a barren desert. However, most of it is absorbed by the atmosphere's ozone layer before reaching the surface.

X-rays

After UV come X-rays, which are also ionizing, but due to their higher energies they can also interact with matter by means of the Compton effect. Hard X-rays have shorter wavelengths than soft X-rays. As they can pass through most substances, X-rays can be used to 'see through' objects, most notably diagnostic X-ray images in medicine (a process known as radiography), as well as for high-energy physics and astronomy. Neutron stars and accretion disks around black holes emit X-rays, which enable us to study them. X-rays are given off by stars and are strongly emitted by some types of nebulae.

Gamma rays

After hard X-rays come gamma rays, which were discovered by Paul Villard in 1900. These are the most energetic photons, having no defined lower limit to their wavelength. They are useful to astronomers in the study of high energy objects or regions, and find a use with physicists thanks to their penetrative ability and their production from radioisotopes. Gamma rays are also used for the irradiation of food and seed for sterilization, and in medicine they are used in radiation cancer therapy and some kinds of diagnostic imaging such as PET scans. The wavelength of gamma rays can be measured with high accuracy by means of Compton scattering.

Note that there are no precisely defined boundaries between the bands of the electromagnetic spectrum. Radiation of some types have a mixture of the properties of those in two regions of the spectrum. For example, red light resembles infrared radiation in that it can resonate some chemical bonds.

Directed-Energy Weapon

A **directed-energy weapon (DEW)** emits energy in an aimed direction without the means of a projectile. It transfers energy to a target for a desired effect. Intended effects may be non-lethal or lethal. Some such weapons are real, or are under active research and development.

The energy can come in various forms:

- Electromagnetic radiation, in lasers or masers
 - Heat
- Particles with mass, in particle beam weapons
- Sound, in sonic weapons

Some such weapons, perhaps most, at present only appear in science fiction, non-functional toys, film props or animation.

In science fiction, these weapons are sometimes known as **death rays** or **rayguns** and are usually portrayed as projecting energy at a person or object to kill or destroy. Many modern examples of science fiction have more specific names for directed energy weapons, due to research advances.

Operational advantages

Laser weapons could have several main advantages over conventional weaponry:

- Laser beams travel at the speed of light, so there is no need (except over very long distances) for users to compensate for target movement when firing over long distances. Consequently, evading a laser after it has been fired is impossible.
- Light has no mass, so is little influenced by gravity, so that long range projection requires little compensation. Other aspects such as wind speed can be neglected at most times, unless shooting through clouds.

- Lasers can change frequency to provide an active area that can be much smaller or larger than projectile weaponry.
- Given a sufficient power source, laser weapons could essentially have limitless ammunition.
- Because light has a practically nil ratio (exactly $1/c$) of momentum to energy, lasers produce negligible recoil.
- The operational range of a laser weapon can be much larger than that of a ballistic weapon, depending on atmospheric conditions and power level.

Modern ballistic weapons commonly feature systems to counter many undesirable side-effects mentioned for them in the above comparison. As such it follows that laser weapons advantage over ballistics, could end up more about elegance and cost.

Problems and considerations

Blooming

Laser beams begin to cause plasma breakdown in the air at energy densities of around a megajoule per cubic centimeter. This effect, called "blooming," causes the laser to defocus and disperse energy into the atmosphere. Blooming can be more severe if there is fog, smoke, or dust in the air.

Reducing blooming:

- Spread the beam across a large, curved mirror that focuses the power on the target, to keep energy density en route too low for blooming to happen. This requires a large, very precise, fragile mirror, mounted somewhat like a searchlight, requiring bulky machinery to slew the mirror to aim the laser.
- Use a phased array. For typical laser wavelengths this method requires billions of micrometre-size antennae. No way to make these is known. Phased arrays could theoretically also perform phase-conjugate amplification (see below). Phased arrays do not require mirrors or lenses, can be made flat and thus do not require a turret-like system (as in "spread beam") to be aimed, though range will suffer at extreme angles (that is, the angle the beam forms to the surface of the phased array).
- Use a phase-conjugate laser system. Here, a "finder" or "guide" laser illuminates the target. Any mirror-like ("specular") points on the target reflect light that is sensed by the weapon's primary amplifier. The weapon then amplifies inverted waves in a positive feedback loop, destroying the target with shockwaves as the specular regions evaporate. This avoids blooming because the waves from the target passed through the blooming, and therefore show the most conductive optical path; this automatically corrects for the distortions caused by blooming. Experimental systems using this method usually use special chemicals to form a "phase conjugate mirror." In most systems, the mirror overheats dramatically at weapon-useful power levels.
- Use a very short pulse that finishes before blooming interferes.

Evaporated target material

Another problem with weaponized lasers is that the evaporated material from the target's surface begins to shade. There are several approaches to this problem:

- Induce a standing shockwave in the ablation cloud. The shockwave then continues to perform damage.
- Scan the target faster than the shockwave propagates
- Induce plasmic optical mixing at the target. Modulate the transparency of the target's ablation cloud to one laser by another laser, perhaps by tuning the laser to the absorption spectra of the ablation cloud, and inducing population inversion in the cloud. The other laser then induces local lasing in the ablation cloud. The beat frequency that results can induce frequencies that penetrate the ablation cloud.

High power consumption

One major problem with laser weapons (and directed-energy weapons in general) is their high electric energy requirements. Existing methods of storing, conducting, transforming, and directing energy are inadequate to produce a convenient hand-held weapon. Existing lasers waste much energy as heat, requiring still-bulky cooling equipment to avoid overheating damage. Air cooling could yield an unacceptable delay between shots. These problems, which severely limit laser weapon practicality at present, might be offset by:

1. Cheap high-temperature superconductors to make the weapon more efficient.
2. More convenient high volume electricity storage/generation. Part of the energy could be used to cool the device.

Chemical lasers use energy from a suitable chemical reaction instead. Chemical oxygen iodine laser (hydrogen peroxide with iodine) and deuterium fluoride laser (atomic fluorine reacting with deuterium) are two laser types capable of megawatt-range continuous beam output. Managing chemical fuel presents other problems, so the problems of cooling and overall inefficiency remain.

This problem could also be lessened if the weapon were mounted either at a defensive position near a power plant, or on board a large, possibly nuclear powered, water-going ship. A ship would have the advantage of water for cooling.

Beam absorption

A laser beam or particle beam passing through air can be absorbed or scattered by rain, snow, dust, fog, smoke, or similar visual obstructions that a bullet would easily penetrate. This effect adds to blooming problems and makes the dissipation of energy into the atmosphere worse.

The wasted energy can disrupt cloud development since the impact wave creates a "tunneling effect". Engineers from MIT and the U.S. Army are looking into using this effect for precipitation management.

Lack of indirect fire capabilities

Indirect fire, as used in artillery warfare, can reach a target behind a hill, but is not feasible with line-of-sight DEWs. Possible alternatives are to mount the lasers (or perhaps just reflectors) on airborne or space-based platforms.

Lasers



A USAF Boeing YAL-1 airborne laser

Lasers are often used for sighting, ranging and targeting for guns; but the laser beam is not the source of the weapon's firepower.

Laser weapons usually generate brief high-energy pulses. A one megajoule laser pulse delivers roughly the same energy as 200 grams of high explosive, and has the same basic

effect on a target. The primary damage mechanism is mechanical shear, caused by reaction when the surface of the target is explosively evaporated.

Most existing weaponized lasers are gas dynamic lasers. Fuel, or a powerful turbine, pushes the lasing media through a circuit or series of orifices. The high-pressures and heating cause the medium to form a plasma and lase. A major difficulty with these systems is preserving the high-precision mirrors and windows of the laser resonating cavity. Most systems use a low-powered "oscillator" laser to generate a coherent wave, and then amplify it. Some experimental laser amplifiers do not use windows or mirrors, but have open orifices, which cannot be destroyed by high energies.

Some lasers are used as non-lethal weapons, such as dazzlers which are designed to temporarily blind or distract.

Specific examples include:

- The Zeus laser weapon is the first laser and the first energy weapon of any type to be given actual use on a battlefield. It is used for neutralizing mines and unexploded ordnance.
- Laser Area Defense System.
- The Mid-Infrared Advanced Chemical Laser (MIRACL) is an experimental U.S. Navy deuterium fluoride laser and was tested against an Air Force satellite in 1997.
- Personnel Halting and Stimulation Response, or PHaSR, is a non-lethal hand-held weapon developed by the United States Air Force. Its purpose is to "dazzle" or stun a target. It was developed by Air Force's Directed Energy Directorate.
- Tactical High Energy Laser (THEL) is a weaponized deuterium fluoride laser developed in a joint research project by Israel and the U.S. It is designed to shoot down aircraft and missiles.
- The U.S. Air Force's Airborne Laser, or Advanced Tactical Laser, is a plan to mount a CO₂ gas laser or COIL chemical laser on a modified Boeing 747 to shoot down missiles.
- Northrop Grumman has announced the availability of a high-energy solid-state laser weapon system that they call FIRESTRIKE. The system is modular, using 15 kW modules that can be combined to provide various levels of power.
- Portable Efficient Laser Testbed (PELT)
- Laser AirCraft CounterMeasures (ACCM)

Electrolaser

An electrolaser lets blooming occur, and then sends a powerful electric current down the conducting ionized track of plasma so formed, somewhat like lightning. It functions as a giant high energy long-distance version of the Taser or stun gun.

Radio frequency

High-energy radio-frequency weapons (HERF) work on the same principles as microwave ovens, have also shown potential.

On January 25, 2007 the US Army unveiled a device mountable on a small armored vehicle (HMMWV). It resembles a planar array. It can make people feel as if the skin temperature is around 130 °F (54 °C) from around 500 yards (460 m) away. Full scale production of such a weapon is not expected until at least 2010. It is probably most usefully deployed as an Active Denial System.

Microwaves

Microwave guns powerful enough to injure humans are possible:

- Active Denial System is a millimeter wave source that heats the water in the target's skin and thus causes incapacitating pain. It is being developed by the U.S. Air Force Research Laboratory and Raytheon for riot-control duty. Though intended to cause severe pain while leaving no lasting damage, some concern has been voiced as to whether the system could cause irreversible damage to the eyes. There has yet to be testing for long-term side effects of exposure to the microwave beam. It can also destroy unshielded electronics. The device comes in various sizes including attached to a humvee.
- Vigilant Eagle is an airport defense system that directs high-frequency microwaves towards any projectile that is fired at an aircraft. The system consists of a missile-detecting and tracking subsystem (MDT), a command and control system, and a scanning array. The MDT is a fixed grid of passive infrared (IR) cameras. The command and control system determines the missile launch point. The scanning array projects microwaves that disrupt the surface-to-air missile's guidance system, deflecting it from the aircraft.

Pulsed Energy Projectile

Pulsed Energy Projectile or PEP systems emit an infrared laser pulse which creates rapidly expanding plasma at the target. The resulting sound, shock and electromagnetic waves stun the target and cause pain and temporary paralysis. The weapon is under development and is intended as a non-lethal weapon in crowd control.

Particle beam weapons

Particle beam weapons can use charged or neutral particles, and can be either endoatmospheric or exoatmospheric. Particle beams as beam weapons are theoretically possible, but practical weapons have not been demonstrated. Certain types of particle beams have the advantage of being self-focusing in the atmosphere.

Blooming is also a problem in particle beam weapons. Energy that would otherwise be focused on the target spreads out; the beam becomes less effective:

- Thermal blooming occurs in both charged and neutral particle beams, and occurs when particles bump into one another under the effects of thermal vibration, or bump into air molecules.
- Electrical blooming occurs only in charged particle beams, as ions of like charge repel one another.

Plasma weapons

Plasma weapons fire a beam, bolt, or stream of plasma, which is an excited state of matter consisting of atomic electrons & nuclei and free electrons if ionized, or other particles if pinched.

The MARAUDER (*Magnetically Accelerated Ring to Achieve Ultra-high Directed Energy and Radiation*) used the Shiva Star project (a high energy capacitor bank which provided the means to test weapons and other devices requiring brief and extremely large amounts of energy) to accelerate a toroid of plasma at a significant percentage of the speed of light.

Electric beam in a vacuum

In a vacuum (e.g. in space), an electric discharge can travel a potentially unlimited distance at a velocity slightly slower than the speed of light. This is because there is no significant electric resistance to the flow of electric current in a vacuum. This would make such devices useful to destroy the electrical and electronic parts of satellites and spacecraft. However, in a vacuum the electric current cannot ride a laser beam, and some other means must be used to keep the electron beam on track and to prevent it from dispersing.

Speed of the weapon

The speed of the energy weapon is determined by the density of the beam. If it is very dense then it is very powerful, but a particle beam moves much slower than the speed of light. Its speed is determined by mass, power, density, or particle/energy density.

Sonic weapons

Cavitation, which affects gas nuclei in human tissue, and heating can result from exposure to ultrasound and can damage tissue and organs. Studies have found that exposure to high intensity ultrasound at frequencies from 700 kHz to 3.6 MHz can cause lung and intestinal damage in mice. Heart rate patterns following vibroacoustic stimulation have resulted in serious arterial flutter and bradycardia. Researchers have concluded that generating pain through the auditory system using high intensity sound risked permanent hearing damage.

A multi-organization research program involved high intensity audible sound experiments on human subjects. Extra-aural (unrelated to hearing) bioeffects on various internal organs and the central nervous system included auditory shifts, vibrotactile sensitivity change, muscle contraction, cardiovascular function change, central nervous system effects, vestibular (inner ear) effects, and chest wall/lung tissue effects. Researchers found that low frequency sonar exposure could result in significant cavitations, hypothermia, and tissue shearing. Follow-on experiments were not recommended.

Tests performed on mice show the threshold for both lung and liver damage occurs at about 184 dB. Damage increases rapidly as intensity is increased. Noise-induced neurological disturbances in humans exposed to continuous low frequency tones for durations longer than 15 minutes involved development of immediate and long term problems affecting brain tissue. The symptoms resembled those of individuals who had suffered minor head injuries. One theory for a causal mechanism is that the prolonged sound exposure resulted in enough mechanical strain to brain tissue to induce an encephalopathy.

History

Ancient inventors

According to legend, the concept of the "burning mirror" or *death ray* began with Archimedes who created a mirror with an adjustable focal length (or more likely, a series of mirrors focused on a common point) to focus sunlight on ships of the Roman fleet as they invaded Syracuse, setting them on fire. Historians point out that the earliest accounts of the battle did not mention a "burning mirror", but merely stated that Archimedes's ingenuity combined with a way to hurl fire were relevant to the victory. Some attempts to replicate this feat have had some success (though not on either of two attempts by the *MythBusters* television program). In particular, an experiment by students at MIT showed that a mirror-based weapon was at least possible, if not necessarily practical.

A new paper titled 'The Math Behind Burning Mirrors' shows that spherical mirrored surfaces can concentrate light by 100,000s of orders. The devices are almost flat and have focal lengths of 50 meters or more. This is more than adequate to perform the burning feat of Syracuse reported by so many ancient scholars. The methods of construction were also within the capabilities of the ancient Greeks.

Beyond this the devices have hundreds of other applications in antiquity

Robert Watson-Watt

In 1935 the British Air Ministry asked Robert Watson-Watt of the Radio Research Station whether a "death ray" was possible. He and colleague Arnold Wilkins quickly concluded that it was not feasible, but as a consequence suggested using radio for the

detection of aircraft and this started the development of radar in Britain. See: History of radar#Robert Watson-Watt.

Engine-stopping rays, urban legend made real

Engine-stopping rays are a variant that occurs in fiction and myth. Such stories were circulating in Britain around 1938. The tales varied but in general terms told of tourists whose car engine suddenly died and were then approached by a German soldier who told them that they had to wait. The soldier returned a short time later to say that the engine would now work and the tourists drove off. A possible origin of some of these stories arises from the testing of the television transmitter in Feldberg, Germany. Because electrical noise from car engines would interfere with field strength measurements, sentries would stop all traffic in the vicinity for the twenty minutes or so needed for a test. A distorted retelling of the events might give rise to the idea that a transmission killed the engine

A shoulder-mounted engine-stopping weapon was a central plot element in episode 303 of BBC espionage drama serial *Spooks*, in which it was referred to as an "engine killer".

Tesla

Nikola Tesla (1856–1943) was a noted inventor, scientist and electrical engineer. He invented Tesla coils, transformers, alternating current electrical generators and was the first early pioneer of radio technology. Tesla worked on plans for a directed-energy weapon from the early 1900s until his death. In 1937, Tesla composed a treatise entitled *The Art of Projecting Concentrated Non-dispersive Energy through the Natural Media* concerning charged particle beams.

Tesla was noted for claiming that he had developed what he called a "teleforce" weapon, or death ray. This death ray could "send concentrated beams of particles through the free air, of such tremendous energy that they will bring down a fleet of 10,000 enemy airplanes at a distance of 250 miles (400 km) from a defending nation's border and will cause armies of millions to drop dead in their tracks", as said in an article. He offered this invention to the U.S. War Department and to several European countries without success. Various conspiracy theories persist regarding the nature of this device and the whereabouts of Tesla's model or schematics for it. Tesla's 1917 proposal for Directed Energy submarine warfare is eerily similar to a 2008 US Department of Defense proposal.

German World War II experimental weapons

In the later phases of World War II, Nazi Germany increasingly put its hopes on research into technologically revolutionary secret weapons, the *Wunderwaffen*.

Among the directed-energy weapons the Nazis investigated were X-Ray Beam Weapons developed under Heinz Schmellenmeier, Richard Gans and Fritz Houtermans. They built

an electron accelerator called Rheotron (invented by Max Steenbeck at Siemens-Schuckert in the 1930s, these were later called Betatrons by the Americans) to generate hard X ray synchrotron beams for the Reichsluftfahrtministerium (RLM). The intent was to pre-ionize ignition in Aircraft engines and hence serve as anti-aircraft DEW and bring planes down into the reach of the FLAK. The Rheotron was captured by the Americans in Burggrub on April 14, 1945.

Another approach was Ernst Schiebolds 'Röntgenkanone' developed from 1943 in Großostheim near Aschaffenburg. The Company Richert Seifert & Co from Hamburg delivered parts.

The Third Reich further developed sonic weaponry, using parabolic reflectors to project sound waves of destructive force. Microwave Weapons were investigated together with the Japanese.

Strategic Defense Initiative

In the 1980s, U.S. President Ronald Reagan proposed the Strategic Defense Initiative (SDI) program, which was nicknamed *Star Wars*. It suggested that lasers, perhaps space-based X-ray lasers, could destroy ICBMs in flight. Though the strategic missile defense concept has continued to the present under the Missile Defense Agency, most of the directed-energy weapon concepts were shelved.

Iraq War

During Iraq War, electromagnetic weapons, including high power microwaves were used by U.S. to disrupt and destroy the Iraqi electronic systems and may have been used for other purposes. Types and magnitudes of exposure to electromagnetic fields are unknown.

Non-lethal weapons

The TECOM Technology Symposium in 1997 concluded on non-lethal weapons, "Determining the target effects on personnel is the greatest challenge to the testing community," primarily because "the potential of injury and death severely limits human tests."

Also, "directed energy weapons that target the central nervous system and cause neurophysiological disorders may violate the Certain Conventional Weapons Convention of 1980. Weapons that go beyond non-lethal intentions and cause "superfluous injury or unnecessary suffering" may also violate the Protocol I to the Geneva Conventions of 1977."

Some common bio-effects of non-lethal electromagnetic weapons include:

- Pain

- Difficulty breathing
- Vertigo
- Nausea
- Disorientation
- Other systemic discomfort.

Interference with breathing poses the most significant, potentially lethal results.

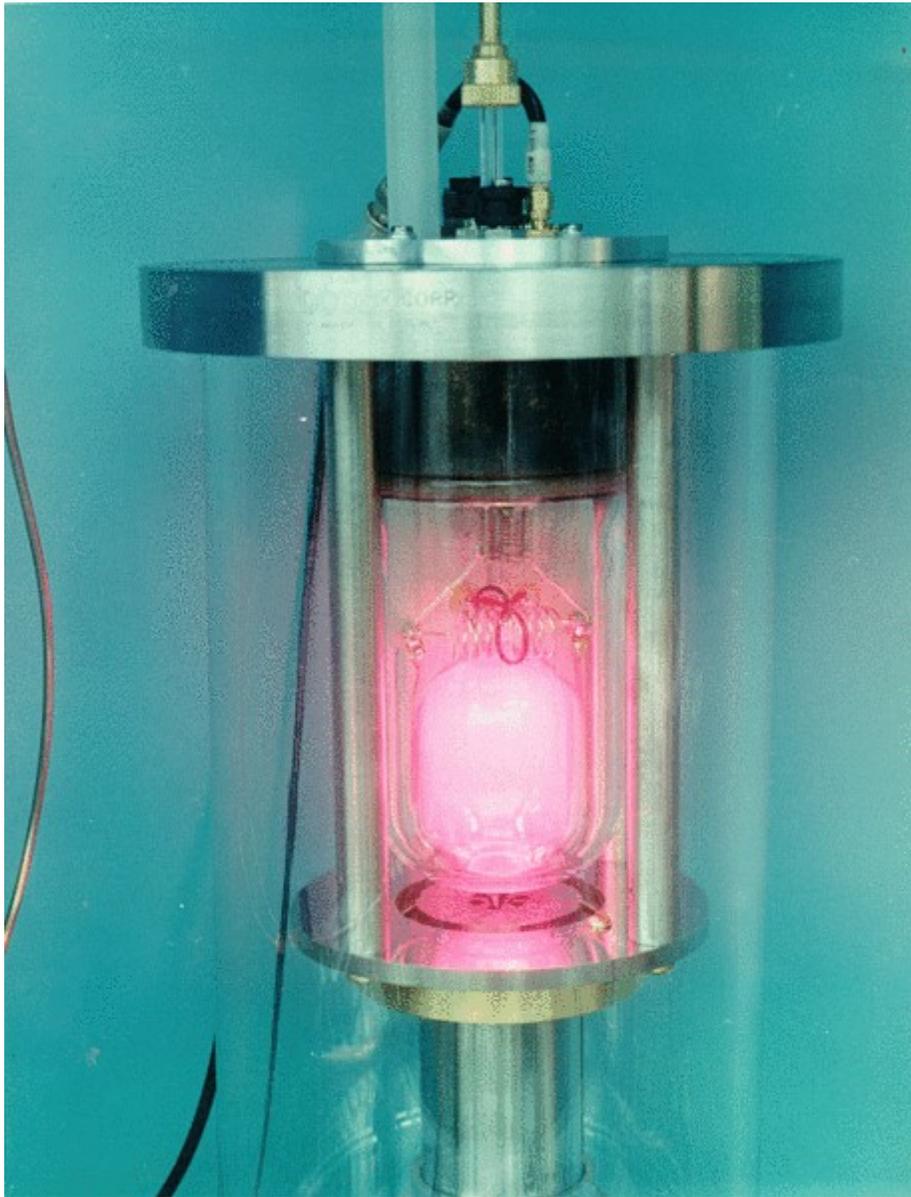
Light and repetitive visual signals can induce epileptic seizures. Vection and motion sickness can also occur.

Cruise ships are known to use sonic weapons to drive off pirates.

WWT

Chapter- 5

Maser & Particle Beam Weapon



A hydrogen radio frequency discharge, the first element inside a hydrogen maser.

A **maser** is a device that produces coherent electromagnetic waves through amplification by stimulated emission. Historically, “maser” derives from the original, upper-case acronym **MASER** stands for "**M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation". The lower-case usage arose from technological development having rendered the original denotation imprecise, because contemporary masers emit EM waves (microwave and radio frequencies) across a broader band of the electromagnetic spectrum; thus, the physicist Charles H. Townes’s suggested usage of “**m**olecular” replacing “microwave”, for contemporary linguistic accuracy. In 1957, when the optical coherent oscillator was first developed, it was denominated *optical maser*, but usually called laser (Light Amplification by Stimulated Emission of Radiation), the acronym Gordon Gould established in 1957.

History

Theoretically, the principle of the maser was described by Nikolay Basov and Alexander Prokhorov from Lebedev Institute of Physics at an *All-Union Conference on Radio-Spectroscopy* held by USSR Academy of Sciences in May 1952. They subsequently published their results in October 1954. Independently, Charles H. Townes, J. P. Gordon, and H. J. Zeiger built the first maser at Columbia University in 1953. The device used stimulated emission in a stream of energized ammonia molecules to produce amplification of microwaves at a frequency of 24 gigahertz. Townes later worked with Arthur L. Schawlow to describe the principle of the *optical maser*, or *laser*, which Theodore H. Maiman first demonstrated in 1960. For their research in this field Townes, Basov, and Prokhorov were awarded the Nobel Prize in Physics in 1964.

Technology

The maser is based on the principle of stimulated emission proposed by Albert Einstein in 1917. When atoms have been put into an excited energy state, they can amplify radiation at the proper frequency. By putting such an amplifying medium in a resonant cavity, feedback is created that can produce coherent radiation.

Some common types of masers

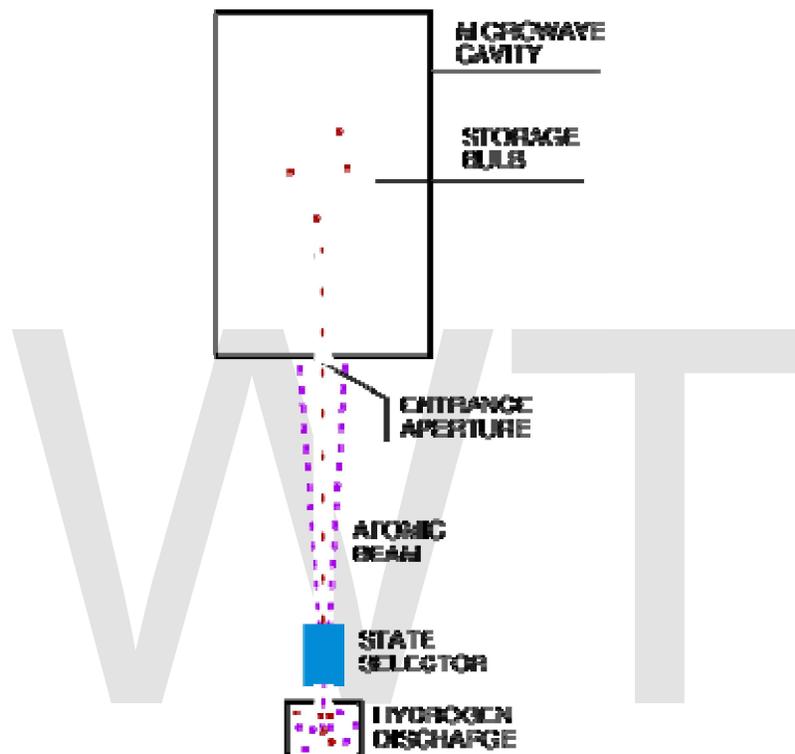
- Atomic beam masers
 - Ammonia maser
 - Free Electron Maser
 - Hydrogen maser
- Gas masers
 - Rubidium maser
- Solid State masers
 - Ruby maser

The dual noble gas maser is an example of a masing medium which is nonpolar.

Uses

Masers serve as high precision frequency references. These "atomic frequency standards" are one form of atomic clock. They are also used as electronic amplifiers in radio telescopes. Masers are being developed as directed-energy weapons.

Hydrogen maser



A hydrogen maser.

Today, the most important type of maser is the hydrogen maser which is currently used as an atomic frequency standard. Together with other types of atomic clocks, they constitute the "Temps Atomique International" or TAI. This is the international time scale, which is coordinated by the Bureau International des Poids et Mesures, or BIPM.

It was Norman Ramsey and his colleagues who first realized this device. Today's masers are identical to the original design. The maser oscillation relies on stimulated emission between two hyperfine levels of atomic hydrogen. Here is a brief description of how it works:

- First, a beam of atomic hydrogen is produced. This is done by submitting the gas at low pressure to an RF discharge.

- The next step is "state selection"—in order to get some stimulated emission, it is necessary to create a population inversion of the atoms. This is done in a way that is very similar to the famous Stern-Gerlach experiment. After passing through an aperture and a magnetic field, many of the atoms in the beam are left in the upper energy level of the lasing transition. From this state, the atoms can decay to the lower state and emit some microwave radiation.
- A high quality factor microwave cavity confines the microwaves and reinjects them repeatedly into the atom beam. The stimulated emission amplifies the microwaves on each pass through the beam. This combination of amplification and feedback is what defines all oscillators. The resonant frequency of the microwave cavity is exactly tuned to the hyperfine structure of hydrogen: 1420 405 751.768 Hz.
- A small fraction of the signal in the microwave cavity is coupled into a coaxial cable and then sent to a coherent receiver.
- The microwave signal coming out of the maser is very weak (a few pW). The frequency of the signal is fixed and *extremely* stable. The coherent receiver is used to amplify the signal and change the frequency. This is done using a series of phase-locked loops and a high performance quartz oscillator.

Astrophysical masers

Maser-like stimulated emission also occurs in nature in interstellar space, and is frequently called superradiant emission to distinguish it from laboratory masers. Such emission is observed from molecules such as water (H₂O), hydroxyl radicals (OH), methanol (CH₃OH), formaldehyde (CH₂O), and silicon monoxide (SiO). Water molecules in star-forming regions can undergo a population inversion and emit radiation at 22 GHz, creating the brightest spectral line in the radio universe. Some water masers also emit radiation from a vibrational mode at 96 GHz.

Extremely powerful masers, associated with active galactic nuclei, are known as megamasers and are up to a million times more powerful than stellar masers.

Terminology

The meaning of the term *maser* has changed slightly since its introduction. Initially the acronym was universally given as "microwave amplification by stimulated emission of radiation," which described devices which emitted in the microwave region of the electromagnetic spectrum. The principle of stimulated emission has since been extended to more devices and frequencies, and so the original acronym is sometimes modified, as suggested by Charles H. Townes, to "*molecular* amplification by stimulated emission of radiation." Some have asserted that Townes's efforts to extend the acronym in this way

were primarily motivated by the desire to increase the importance of his invention, and his reputation in the scientific community.

When the laser was developed, Townes and Schawlow and their colleagues at Bell Labs pushed the use of the term *optical maser*, but this was largely abandoned in favor of *laser*, coined by their rival Gordon Gould. In modern usage, devices that emit in the X-ray through infrared portions of the spectrum are typically called lasers, and devices that emit in the microwave region and below are commonly called *masers*, regardless of whether they emit microwaves or other frequencies.

Gould originally proposed distinct names for devices that emit in each portion of the spectrum, including *grasers* (gamma ray lasers), *xasers* (x-ray lasers), *uvasers* (ultraviolet lasers), *lasers* (visible lasers), *irasers* (infrared lasers), *masers* (microwave masers), and *rasers* (RF masers). Most of these terms never caught on, however, and all have now become (apart from in science fiction) obsolete except for *maser* and *laser*.

Particle beam weapon

A **particle beam weapon** uses an ultra-high-energy beam of atoms or electrons (i.e. a particle beam) to damage a material target by hitting it, and thus disrupting its atomic and molecular structure. A particle beam weapon is a type of directed-energy weapon, which directs energy in a particular direction by a means of particle projectiles with mass. Some of these weapons are real or practicable; some are science fiction.

An **electron particle beam weapon** works by disrupting electric circuits and electronic devices in its targets. If any living animals or persons were to be caught by the electric discharge of an electron beam weapon, they would most likely be electrocuted. An electron beam weapon can also damage or melt its target by the electrical resistance heating of the target.

Beam generation

A neutral particle beam weapon ionizes hydrogen gas by either stripping an electron off of each hydrogen atom, or by allowing each hydrogen atom to capture an extra electron. When hydrogen gains electrons it forms anions; when hydrogen atoms lose electrons they form cations. A particle beam weapon that accelerates anions uses a traveling wave type particle accelerator. In this kind of ion accelerator, the negative ions are released inside a cylindrical ion acceleration chamber. This chamber has an electrode with an alternating electric charge of up to 1,000,000,000 (10^9) volts inside it.

These stages happen:-

1. While the charge on the electrode is positive, the ions are attracted to the negative charge on the electrode, and thus bunched around it.

2. The alternating voltage switches the charge to negative on the accelerating electrode.
3. The negative charge electrostatically repels the negative ions and accelerates them to near the velocity of light.
4. The resulting high energy beam of anions passes through a chamber filled with low pressure gas.
5. There, collisions with the gas strip the extra electrons from the anions, and thus make the particle beam neutral.
6. The particle beam proceeds straight to its target, and damages it by running into it, and by disrupting the structure of the target with its kinetic energy.

Cyclotron particle accelerators, linear particle accelerators, and synchrotron particle accelerators can accelerate positively charged hydrogen ions until their velocity approaches the speed of light, and each individual ion has a kinetic energy range of 100 MeV to 1000 MeV or more. Then the resulting high energy protons can capture electrons from electron emitter electrodes, and be thus electrically neutralized. This creates an electrically neutral beam of high energy hydrogen atoms, that can proceed in a straight line at near the speed of light to smash into its target and damage it.

The pulsed particle beam emitted by such a weapon may contain up to 1 gigajoule of kinetic energy or more. The speed of a beam approaching that of light (300,000 km/sec) in combination with the energy created by the weapon would negate any realistic means of defending a target against the beam. Target hardening through shielding or materials selection would be impractical or ineffective, especially if the beam could be maintained at full power and precisely focused on the target.

History

Tesla

Nikola Tesla (1856 - 1943) was a noted inventor, scientist and electrical engineer. He invented Tesla coils, alternating current electric generators and was a major early pioneer of radio technology. He was also noted for making some remarkable claims, among them that he had developed what he called a "teleforce" weapon. The press called it a "*peace ray*" or death ray.

In total, the components and methods included :

1. An apparatus for producing manifestations of energy in free air instead of in a high vacuum as in the past. This, according to Tesla in 1934, was accomplished.
2. A mechanism for generating tremendous electrical force. This, according to Tesla, was also accomplished.
3. A means of intensifying and amplifying the force developed by the second mechanism.
4. A new method for producing a tremendous electrical repelling force. This would be the projector, or gun, of the invention.

In 1937, Tesla composed a treatise entitled "*The Art of Projecting Concentrated Non-dispersive Energy through the Natural Media*". This treatise is currently in the Nikola Tesla Museum archive in Belgrade. It described an open ended vacuum tube with a gas jet seal that allowed particles to exit, a method of charging particles to millions of volts, and a method of creating and directing non-dispersive particle streams (through electrostatic repulsion).

Tesla worked on plans for a directed-energy weapon between the early 1900s until the time of his death. Records of his device indicate that it was based on a narrow stream of atomic clusters of liquid mercury or tungsten accelerated via high voltage (by means akin to his magnifying transformer). Tesla gave the following description concerning the *particle gun's* operation:

[The nozzle would] "*send concentrated beams of particles through the free air, of such tremendous energy that they will bring down a fleet of 10,000 enemy airplanes at a distance of 200 miles from a defending nation's border and will cause armies to drop dead in their tracks*".

The weapon could be used against ground based infantry or for anti-aircraft purposes. Tesla tried to interest the US War Department in the device. He also offered this invention to European countries. None of the governments purchased a contract to build the device.

Various theories persist regarding the nature of this device and the whereabouts of Tesla's complete schematics for it. Immediately after his death, his effects were confiscated and the room's safe opened. The FBI never found the schematics nor any prototype. The so-called "*peace ray*" constitutes a part of some conspiracy theories as a means of destruction.

Modern experiments

Several modern experimental particle beam weapons were tested at scientific laboratories such as the Los Alamos National Laboratory in New Mexico by both the United States and the USSR from the 1950s to the 1980s.

The U.S. Defense Strategic Defense Initiative Organization put into development the technology of a neutral particle beam for strategic defense applications. In mid 1989, it was to be part of the Beam Experiments Aboard a Rocket (BEAR) in New Mexico.

Sandia National Laboratories, part of Lockheed Martin Co., in Sandia New Mexico, on Dec. 15, 2008, broke ground on the \$40 million Ion Beam Laboratory at Kirtland Air Force Base. It will house six accelerators and is scheduled for occupancy in 2010.

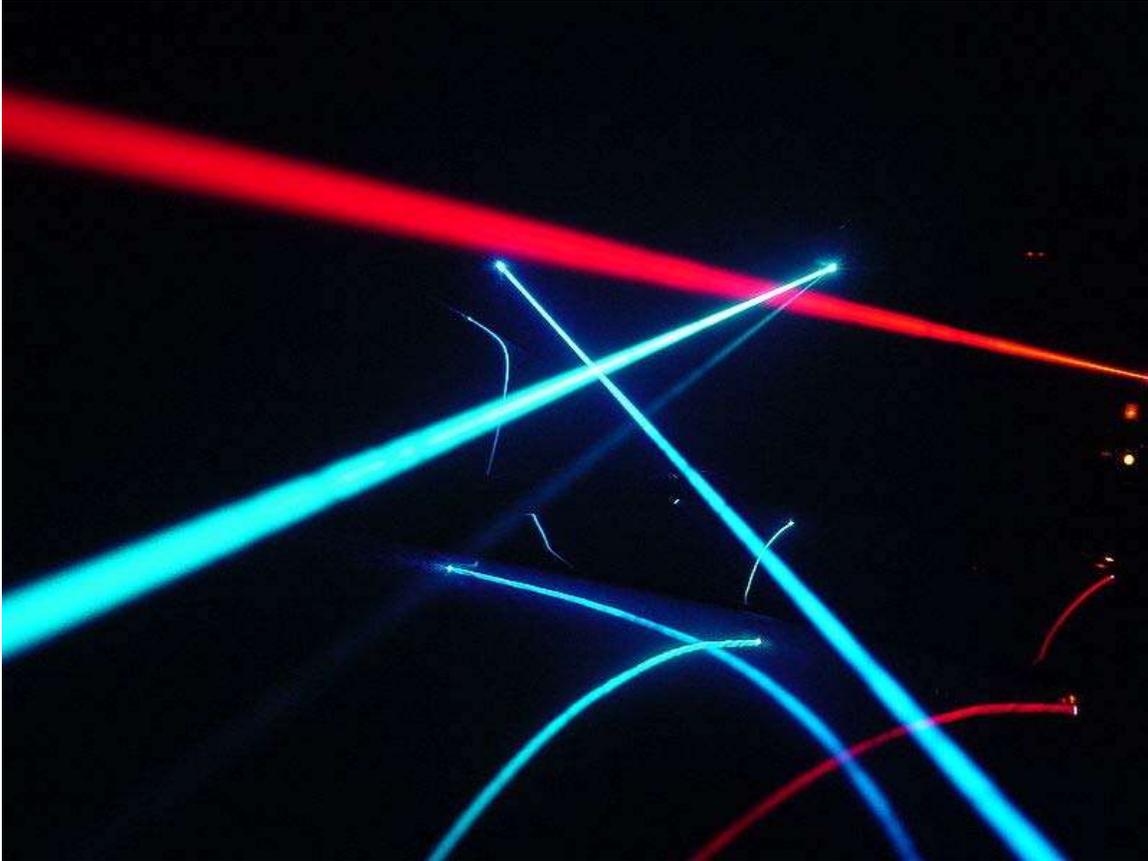
Laser

Laser



United States Air Force laser experiment

Inventor	Charles Hard Townes
Launch year	1960
Availability	Worldwide

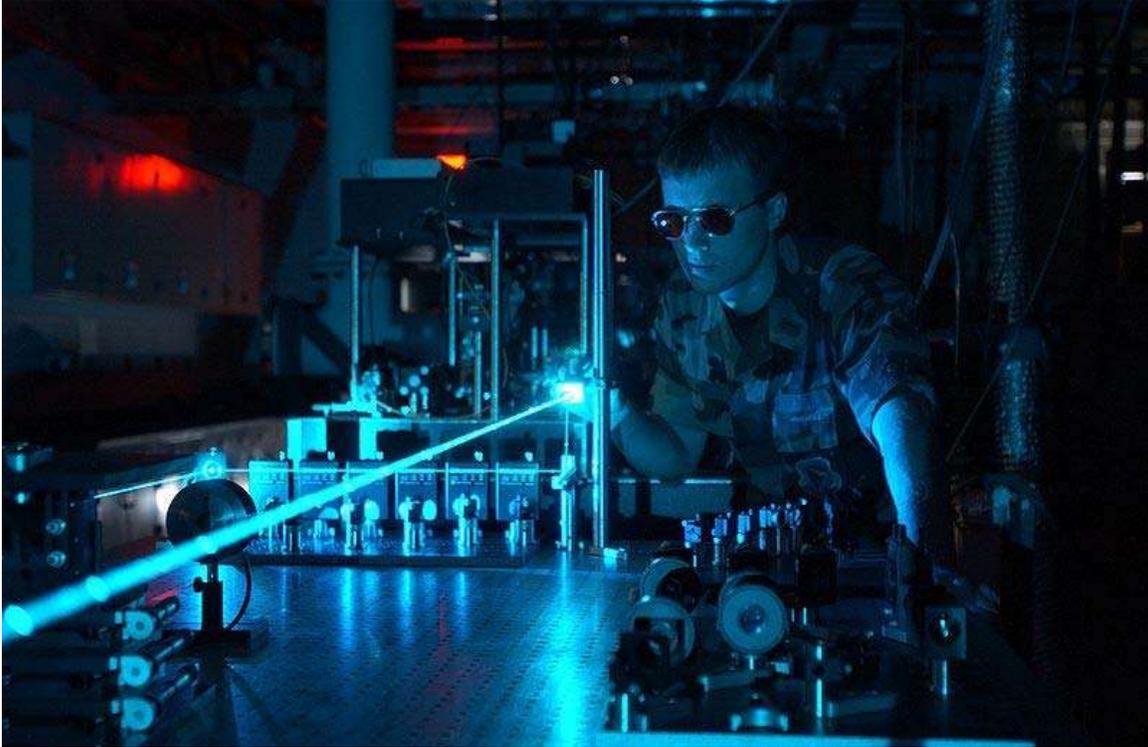


Laser beams in fog, reflected on a car windshield

A **laser** is a device that emits light (electromagnetic radiation) through a process of optical amplification based on the stimulated emission of photons. The term "laser" originated as an acronym for *Light Amplification by Stimulated Emission of Radiation*. The emitted laser light is notable for its high degree of spatial and temporal coherence, unattainable using other technologies.

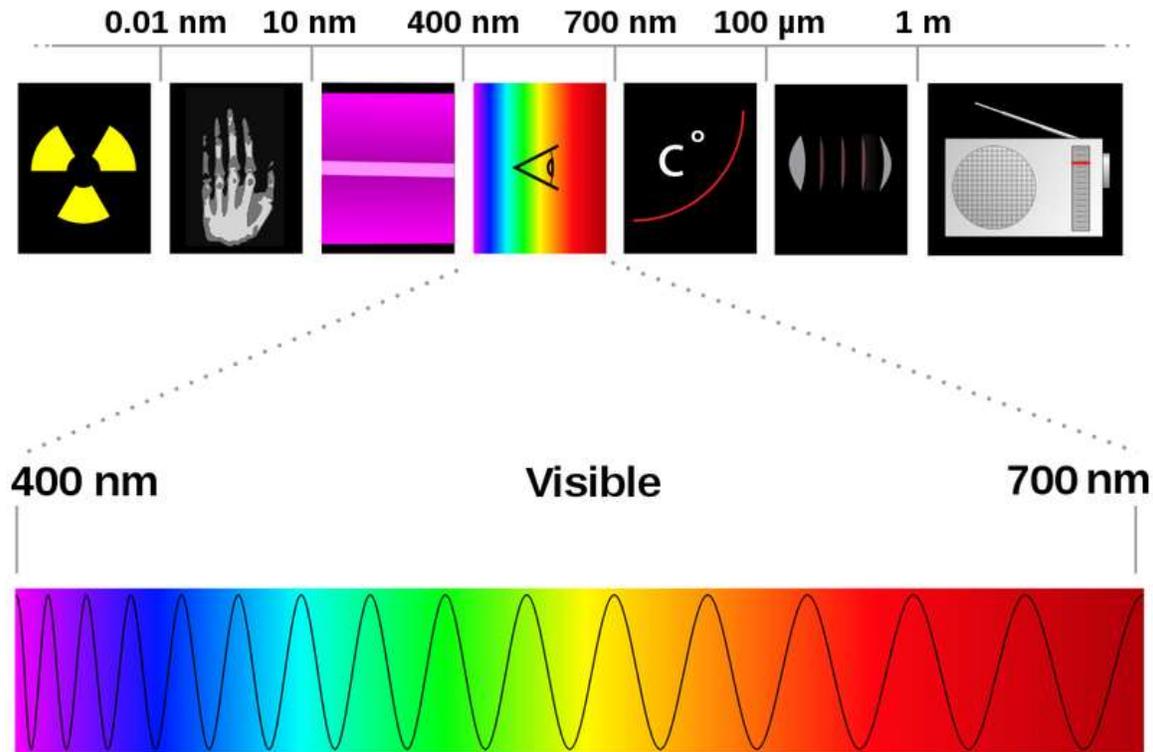
Spatial coherence typically is expressed through the output being a narrow beam which is diffraction-limited, often a so-called "pencil beam." Laser beams can be focused to very tiny spots, achieving a very high irradiance. Or they can be launched into a beam of very low divergence in order to concentrate their power at a large distance.

Temporal (or longitudinal) coherence implies a polarized wave at a single frequency whose phase is correlated over a relatively large distance (the coherence length) along the beam. A beam produced by a thermal or other incoherent light source has an instantaneous amplitude and phase which vary randomly with respect to time and position, and thus a very short coherence length.



Most so-called "single wavelength" lasers actually produce radiation in several *modes* having slightly different frequencies (wavelengths), often not in a single polarization. And although temporal coherence implies monochromaticity, there are even lasers that emit a broad spectrum of light, or emit different wavelengths of light simultaneously. There are some lasers which are not single spatial mode and consequently their light beams diverge more than required by the diffraction limit. However all such devices are classified as "lasers" based on their method of producing that light: stimulated emission. Lasers are employed in applications where light of the required spatial or temporal coherence could not be produced using simpler technologies.

Terminology



From left to right: gamma rays, X-rays, ultraviolet rays, visible spectrum, infrared, microwaves, radio waves. Bottom: enlargement of visible spectrum from violet (400nm) to red (700nm).

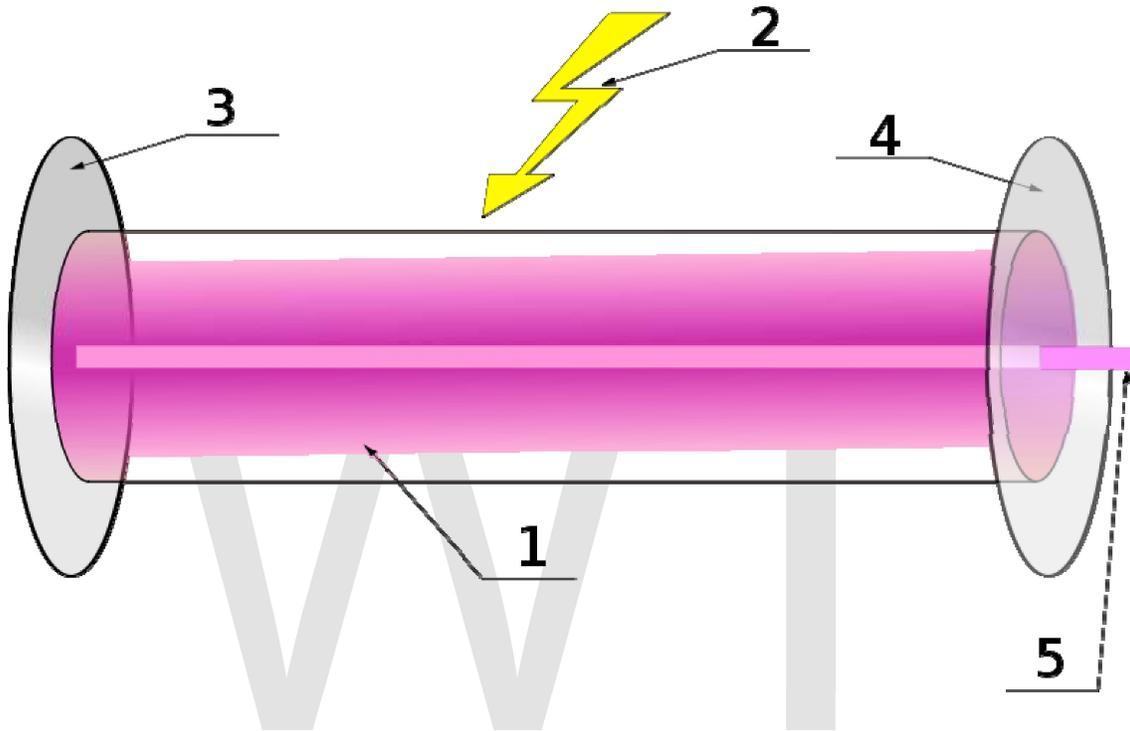
The word *laser* started as an acronym for "light amplification by stimulated emission of radiation", where "light" broadly denotes electromagnetic radiation of any frequency, not only visible light; hence infrared laser, ultraviolet laser, X-ray laser, and so on. Because the microwave predecessor of the laser, the maser, was developed first, devices of this sort operating at microwave and radio frequencies are referred to as "masers" rather than "microwave lasers" or "radio lasers". In the early technical literature, especially at Bell Telephone Laboratories, the laser was called an **optical maser**; this term is now obsolete.

A laser which produces light by itself is technically an optical oscillator rather than an optical amplifier as suggested by the acronym. It has been humorously noted that the acronym LOSER, for "light oscillation by stimulated emission of radiation" would have been more correct. With the widespread use of the original acronym as a common noun, actual optical amplifiers have come to be referred to as "laser amplifiers", notwithstanding the apparent redundancy in that designation.

The back-formed verb *to lase* is frequently used in the field, meaning "to produce laser light," especially in reference to the gain medium of a laser; when a laser is operating it is said to be "lasing." Further use of the words *laser* and *maser* in an extended sense, not

referring to laser technology or devices, can be seen in usages such as *astrophysical maser* and *atom laser*.

Design



Principal components:

1. Gain medium
2. Laser pumping energy
3. High reflector
4. Output coupler
5. Laser beam

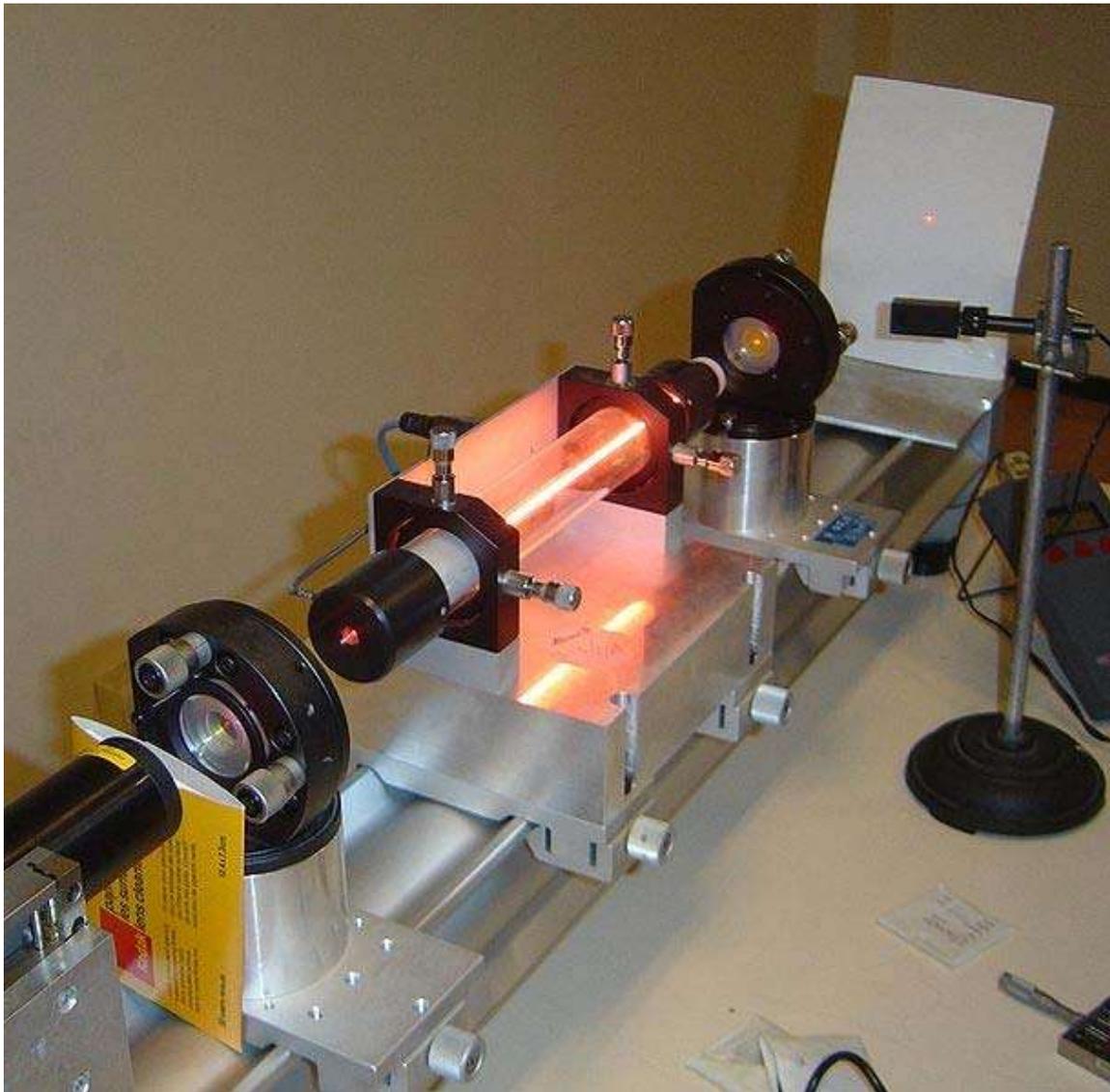
A laser consists of a gain medium inside a highly reflective optical cavity, as well as a means to supply energy to the gain medium. The gain medium is a material with properties that allow it to amplify light by stimulated emission. In its simplest form, a cavity consists of two mirrors arranged such that light bounces back and forth, each time passing through the gain medium. Typically one of the two mirrors, the output coupler, is partially transparent. The output laser beam is emitted through this mirror.

Light of a specific wavelength that passes through the gain medium is amplified (increases in power); the surrounding mirrors ensure that most of the light makes many passes through the gain medium, being amplified repeatedly. Part of the light that is

between the mirrors (that is, within the cavity) passes through the partially transparent mirror and escapes as a beam of light.

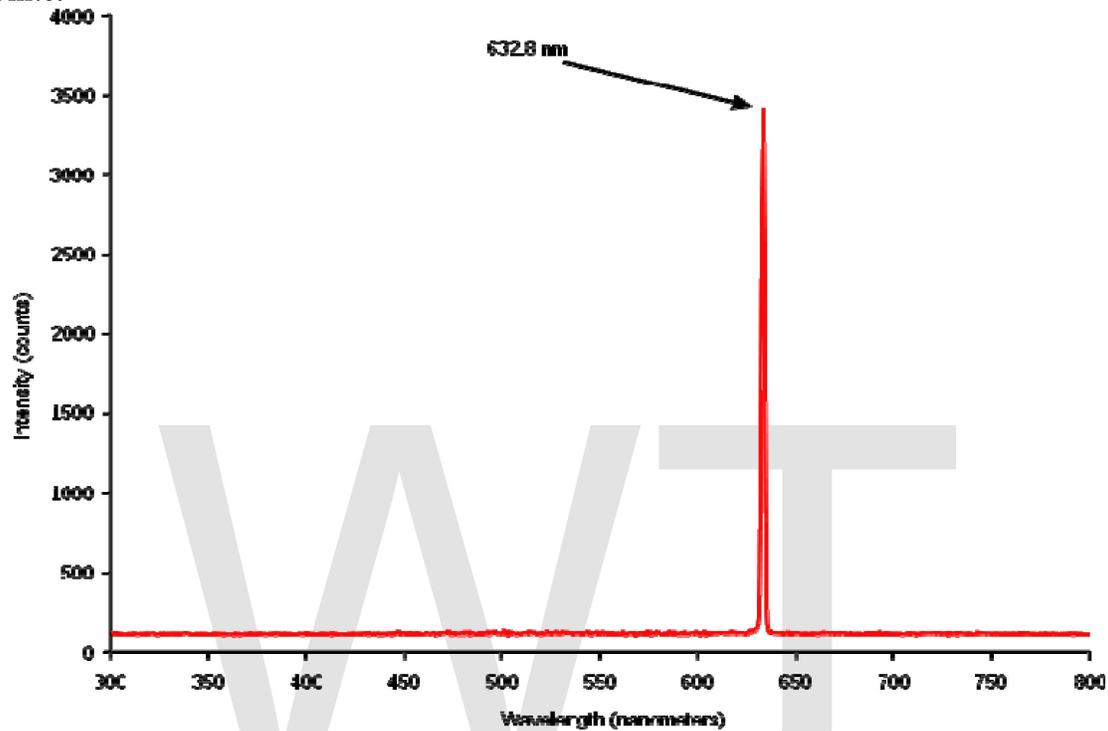
The process of supplying the energy required for the amplification is called pumping. The energy is typically supplied as an electrical current or as light at a different wavelength. Such light may be provided by a flash lamp or perhaps another laser. Most practical lasers contain additional elements that affect properties such as the wavelength of the emitted light and the shape of the beam.

Laser physics



A helium-neon laser demonstration at the Kastler-Brossel Laboratory at Univ. Paris 6. The pink-orange glow running through the center of the tube is from the electric discharge which inadvertently produces incoherent light, just as in a neon tube. That

glowing plasma however also acts as the gain medium through which the internal beam passes as it is reflected in between the two mirrors. Laser radiation output from the front mirror can be seen to produce a tiny (about 1mm in diameter) intense spot on the screen to the right. Although it is a deep and pure red color, spots of laser light are so intense that cameras are typically overexposed and distort their color, often appearing more white.



Spectrum of a helium neon laser illustrating its very high spectral purity (limited by the measuring apparatus). The .002 nm bandwidth of the lasing medium is well over 10,000 times narrower than the spectral width of a light-emitting diode (whose spectrum is shown [here](#) for comparison), with the bandwidth of a single longitudinal mode being much narrower still.

The gain medium of a laser is a material of controlled purity, size, concentration, and shape, which amplifies the beam by the process of stimulated emission. It can be of any state: gas, liquid, solid or plasma. The gain medium absorbs pump energy, which raises some electrons into higher-energy ("excited") quantum states. Particles can interact with light by either absorbing or emitting photons. Emission can be spontaneous or stimulated. In the latter case, the photon is emitted in the same direction as the light that is passing by. When the number of particles in one excited state exceeds the number of particles in some lower-energy state, population inversion is achieved and the amount of stimulated emission due to light that passes through is larger than the amount of absorption. Hence, the light is amplified. By itself, this makes an optical amplifier. When an optical amplifier is placed inside a resonant optical cavity, one obtains a laser.

The light generated by stimulated emission is very similar to the input signal in terms of wavelength, phase, and polarization. This gives laser light its characteristic coherence,

and allows it to maintain the uniform polarization and often monochromaticity established by the optical cavity design.

The optical resonator is sometimes referred to as an "optical cavity", but this is a misnomer: lasers use open resonators as opposed to the literal cavity that would be employed at microwave frequencies in a maser. The resonator typically consists of two mirrors between which a coherent beam of light travels in both directions, reflecting back on itself so that an average photon will pass through the gain medium repeatedly before it is emitted from the output aperture or lost to diffraction or absorption. If the gain (amplification) in the medium is larger than the resonator losses, then the power of the recirculating light can rise exponentially. But each stimulated emission event returns an atom from its excited state to the ground state, reducing the gain of the medium. With increasing beam power the net gain (gain times loss) reduces to unity and the gain medium is said to be saturated. In a continuous wave (CW) laser, the balance of pump power against gain saturation and cavity losses produces an equilibrium value of the laser power inside the cavity; this equilibrium determines the operating point of the laser. If the applied pump power is too small, the gain will never be sufficient to overcome the resonator losses, and laser light will not be produced. The minimum pump power needed to begin laser action is called the *lasing threshold*. The gain medium will amplify any photons passing through it, regardless of direction; but only the photons in a spatial mode supported by the resonator will pass more than once through the medium and receive substantial amplification.

The beam in the cavity and the output beam of the laser, when travelling in free space (or a homogenous medium) rather than waveguides (as in an optical fiber laser), can be approximated as a Gaussian beam in most lasers; such beams exhibit the minimum divergence for a given diameter. However some high power lasers may be multimode, with the transverse modes often approximated using Hermite-Gaussian or Laguerre-Gaussian functions. It has been shown that unstable laser resonators (not used in most lasers) produce fractal shaped beams. Near the beam "waist" (or focal region) it is highly *collimated*: the wavefronts are planar, normal to the direction of propagation, with no beam divergence at that point. However due to diffraction, that can only remain true well within the Rayleigh range. The beam of a single transverse mode (gaussian beam) laser eventually diverges at an angle which varies inversely with the beam diameter, as required by diffraction theory. Thus, the "pencil beam" directly generated by a common helium-neon laser would spread out to a size of perhaps 500 kilometers when shone on the Moon (from the distance of the earth). On the other hand the light from a semiconductor laser typically exits the tiny crystal with a large divergence: up to 50°. However even such a divergent beam can be transformed into a similarly collimated beam by means of a lens system, as is always included, for instance, in a laser pointer whose light originates from a laser diode. That is possible due to the light being of a single spatial mode. This unique property of laser light, spatial coherence, cannot be replicated using standard light sources (except by discarding most of the light) as can be appreciated by comparing the beam from a flashlight (torch) or spotlight to that of almost any laser.

The mechanism of producing radiation in a laser relies on stimulated emission, where energy is extracted from a transition in an atom or molecule. This is a quantum phenomenon discovered by Einstein who derived the relationship between the A coefficient describing spontaneous emission and the B coefficient which applies to absorption and stimulated emission. However in the case of the free electron laser, atomic energy levels are not involved; it appears that the operation of this rather exotic device can be explained without reference to quantum mechanics.

Continuous and pulsed modes of operation

A laser can be classified as operating in either continuous or pulsed mode, depending on whether the power output is essentially continuous over time or whether its output takes the form of pulses of light on one or another time scale. Of course even a laser whose output is normally continuous can be intentionally turned on and off at some rate in order to create pulses of light. When the modulation rate is on time scales much slower than the cavity lifetime and the time period over which energy can be stored in the lasing medium or pumping mechanism, then it is still classified as a "modulated" or "pulsed" continuous wave laser. Most laser diodes used in communication systems fall in that category.

Continuous wave operation

Some applications of lasers depend on a beam whose output power is constant over time. Such a laser is known as *continuous wave (CW)*. Many types of lasers can be made to operate in continuous wave mode to satisfy such an application. Many of these lasers actually lase in several longitudinal modes at the same time, and beats between the slightly different optical frequencies of those oscillations will in fact produce amplitude variations on time scales shorter than the round-trip time (the reciprocal of the frequency spacing between modes), typically a few nanoseconds or less. In most cases these lasers are still termed "continuous wave" as their output power is steady when averaged over any longer time periods, with the very high frequency power variations having little or no impact in the intended application. (However the term is not applied to mode locked lasers, where the *intention* is to create very short pulses at the rate of the round-trip time).

For continuous wave operation it is required for the population inversion of the gain medium to be continually replenished by a steady pump source. In some lasing media this is impossible. In some other lasers it would require pumping the laser at a very high continuous power level which would be impractical or destroy the laser by producing excessive heat. Such lasers cannot be run in CW mode.

Pulsed operation

Pulsed operation of lasers refers to any laser not classified as continuous wave, so that the optical power appears in pulses of some duration at some repetition rate. This encompasses a wide range of technologies addressing a number of different motivations. Some lasers are pulsed simply because they cannot be run in continuous mode.

In other cases the application requires the production of pulses having as large an energy as possible. Since the pulse energy is equal to the average power divided by the repetition rate, this goal can sometimes be satisfied by lowering the rate of pulses so that more energy can be built up in between pulses. In laser ablation for example, a small volume of material at the surface of a work piece can be evaporated if it is heated in a very short time, whereas supplying the energy gradually would allow for the heat to be absorbed into the bulk of the piece, never attaining a sufficiently high temperature at a particular point.

Other applications rely on the peak pulse power (rather than the energy in the pulse), especially in order to obtain nonlinear optical effects. For a given pulse energy, this requires creating pulses of the shortest possible duration utilizing techniques such as Q-switching.

The optical bandwidth of a pulse cannot be narrower than the reciprocal of the pulse width. In the case of extremely short pulses, that implies lasing over a considerable bandwidth, quite contrary to the very narrow bandwidths typical of CW lasers. The lasing medium in some *dye lasers* and *vibronic solid-state lasers* produces optical gain over a wide bandwidth, making a laser possible which can thus generate pulses of light as short as a few femtoseconds (10^{-15} s).

Q-switching

In a Q-switched laser, the population inversion is allowed to build up by introducing loss inside the resonator which exceeds the gain of the medium; this can also be described as a reduction of the quality factor or 'Q' of the cavity. Then, after the pump energy stored in the laser medium has approached the maximum possible level, the introduced loss mechanism (often an electro- or acousto-optical element) is rapidly removed (or that occurs by itself in a passive device), allowing lasing to begin which rapidly obtains the stored energy in the gain medium. This results in a short pulse incorporating that energy, and thus a high peak power.

Mode-locking

A mode-locked laser is capable of emitting extremely short pulses on the order of tens of picoseconds down to less than 10 femtoseconds. These pulses will repeat at the round trip time, that is, the time that it takes light to complete one round trip between the mirrors comprising the resonator. Due to the Fourier limit (also known as energy-time uncertainty), a pulse of such short temporal length has a spectrum spread over a considerable bandwidth. Thus such a gain medium must have a gain bandwidth sufficiently broad to amplify those frequencies. An example of a suitable material is titanium-doped, artificially grown sapphire (Ti:sapphire) which has a very wide gain bandwidth and can thus produce pulses of only a few femtoseconds duration.

Such mode-locked lasers are a most versatile tool for researching processes occurring on extremely short time scales (known as femtosecond physics, femtosecond chemistry and

ultrafast science), for maximizing the effect of nonlinearity in optical materials (e.g. in second-harmonic generation, parametric down-conversion, optical parametric oscillators and the like) due to the large peak power, and in ablation applications. Again, because of the extremely short pulse duration, such a laser will produce pulses which achieve an extremely high peak power.

Pulsed pumping

Another method of achieving pulsed laser operation is to pump the laser material with a source that is itself pulsed, either through electronic charging in the case of flash lamps, or another laser which is already pulsed. Pulsed pumping was historically used with dye lasers where the inverted population lifetime of a dye molecule was so short that a high energy, fast pump was needed. The way to overcome this problem was to charge up large capacitors which are then switched to discharge through flashlamps, producing an intense flash. Pulsed pumping is also required for three-level lasers in which the lower energy level rapidly becomes highly populated preventing further lasing until those atoms relax to the ground state. These lasers, such as the excimer laser and the copper vapor laser, can never be operated in CW mode.

History

Foundations

In 1917, Albert Einstein established the theoretic foundations for the laser and the maser in the paper *Zur Quantentheorie der Strahlung* (On the Quantum Theory of Radiation); via a re-derivation of Max Planck's law of radiation, conceptually based upon probability coefficients (Einstein coefficients) for the absorption, spontaneous emission, and stimulated emission of electromagnetic radiation; in 1928, Rudolf W. Ladenburg confirmed the existences of the phenomena of stimulated emission and negative absorption; in 1939, Valentin A. Fabrikant predicted the use of stimulated emission to amplify "short" waves; in 1947, Willis E. Lamb and R. C. Retherford found apparent stimulated emission in hydrogen spectra and effected the first demonstration of stimulated emission; in 1950, Alfred Kastler (Nobel Prize for Physics 1966) proposed the method of optical pumping, experimentally confirmed, two years later, by Brossel, Kastler, and Winter.

Maser

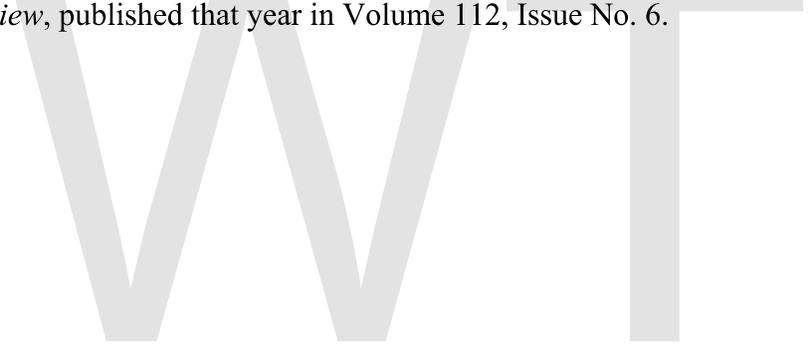
In 1953, Charles Hard Townes and graduate students James P. Gordon and Herbert J. Zeiger produced the first microwave amplifier, a device operating on similar principles to the laser, but amplifying microwave radiation rather than infrared or visible radiation. Townes's maser was incapable of continuous output. Meanwhile, in the Soviet Union, Nikolay Basov and Aleksandr Prokhorov were independently working on the quantum oscillator and solved the problem of continuous-output systems by using more than two energy levels. These gain media could release stimulated emissions between an excited state and a lower excited state, not the ground state, facilitating the maintenance of a

population inversion. In 1955, Prokhorov and Basov suggested optical pumping of a multi-level system as a method for obtaining the population inversion, later a main method of laser pumping.

Townes reports that several eminent physicists — among them Niels Bohr, John von Neumann, Isidor Rabi, Polykarp Kusch, and Llewellyn Thomas — argued the maser violated Heisenberg's uncertainty principle and hence could not work. In 1964 Charles H. Townes, Nikolay Basov, and Aleksandr Prokhorov shared the Nobel Prize in Physics, “for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser–laser principle”.

Laser

In 1957, Charles Hard Townes and Arthur Leonard Schawlow, then at Bell Labs, began a serious study of the infrared laser. As ideas developed, they abandoned infrared radiation to instead concentrate upon visible light. The concept originally was called an "optical maser". In 1958, Bell Labs filed a patent application for their proposed optical maser; and Schawlow and Townes submitted a manuscript of their theoretical calculations to the *Physical Review*, published that year in Volume 112, Issue No. 6.



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Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation.

conceive a tube terminated by optically flat

partially reflecting parallel mirrors. The mirrors might be silvered or multilayer interference reflectors. The latter are ^{almost} lossless and may have an arbitrarily high reflectance depending on the number of layers. ~~a~~ a practical achievement is 98% in the visible for a 7-layer ~~film~~ reflector. Films with closer tolerances than $\frac{1}{100} \lambda$ are not available so if a resonant system is desired, higher reflectance would not be useful. However, for a nonresonant system, the 99.9% reflectances which are possible might be useful.

Consider a plane ^{standing} wave in the tube. There is the effect of a closed cavity; since the ~~tube~~ wavelength is small the diffraction and hence the lateral loss is negligible.

① O.S. Heavens, "Optical Properties of Thin Solid Films" (Butterworths Scientific Publications, London, 1955), p. 220.

JACK GOULD
 Notary Public, State of New York
 No. 09-1021960
 Qualified in Essex County
 Commission Expires March 30, 1958
 Sought to and subscribed before me this 13 day of Nov. 1957
 Gordon Gould

LASER notebook: First page of the notebook wherein Gordon Gould coined the LASER acronym, and described the technologic elements for constructing the device.

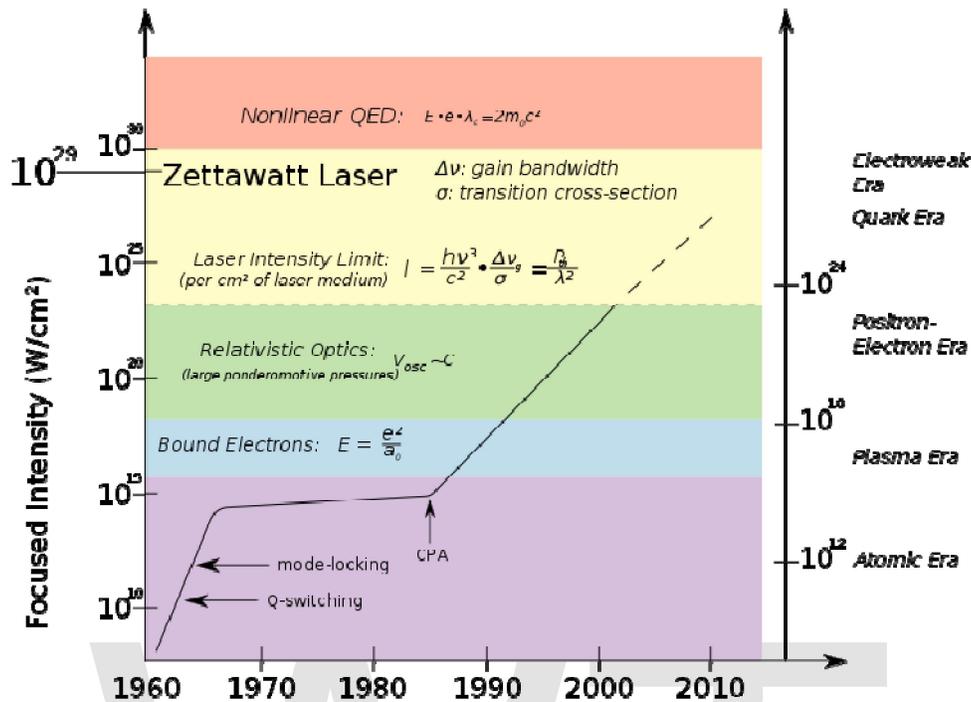
Simultaneously, at Columbia University, graduate student Gordon Gould was working on a doctoral thesis about the energy levels of excited thallium. When Gould and Townes met, they spoke of radiation emission, as a general subject; afterwards, in November 1957, Gould noted his ideas for a "laser", including using an open resonator (later an essential laser-device component). Moreover, in 1958, Prokhorov independently proposed using an open resonator, the first published appearance (the USSR) of this idea. Elsewhere, in the US, Schawlow and Townes had agreed to an open-resonator laser design — apparently unaware of Prokhorov's publications and Gould's unpublished laser work.

At a conference in 1959, Gordon Gould published the term LASER in the paper *The LASER, Light Amplification by Stimulated Emission of Radiation*. Gould's linguistic intention was using the "-aser" word particle as a suffix — to accurately denote the spectrum of the light emitted by the LASER device; thus x-rays: *xaser*, ultraviolet: *uvaser*, et cetera; none established itself as a discrete term, although "raser" was briefly popular for denoting radio-frequency-emitting devices.

Gould's notes included possible applications for a laser, such as spectrometry, interferometry, radar, and nuclear fusion. He continued developing the idea, and filed a patent application in April 1959. The U.S. Patent Office denied his application, and awarded a patent to Bell Labs, in 1960. That provoked a twenty-eight-year lawsuit, featuring scientific prestige and money as the stakes. Gould won his first minor patent in 1977, yet it was not until 1987 that he won the first significant patent lawsuit victory, when a Federal judge ordered the US Patent Office to issue patents to Gould for the optically pumped and the gas discharge laser devices.

In 1960, Theodore H. Maiman constructed the first functioning laser, at Hughes Research Laboratories, Malibu, California, ahead of several research teams, including those of Townes, at Columbia University, Arthur Schawlow, at Bell Labs, and Gould, at the TRG (Technical Research Group) company. Maiman's functional laser used a solid-state flashlamp-pumped synthetic ruby crystal to produce red laser light, at 694 nanometres wavelength; however, the device only was capable of pulsed operation, because of its three-level pumping design scheme. Later in 1960, the Iranian physicist Ali Javan, and William R. Bennett, and Donald Herriot, constructed the first gas laser, using helium and neon that was capable of continuous operation in the infrared (US Patent 3,149,290); later, Javan received the Albert Einstein Award in 1993. Basov and Javan proposed the semiconductor laser diode concept. In 1962, Robert N. Hall demonstrated the first *laser diode* device, made of gallium arsenide and emitted at 850 nm the near-infrared band of the spectrum. Later, in 1962, Nick Holonyak, Jr. demonstrated the first semiconductor laser with a visible emission. This first semiconductor laser could only be used in pulsed-beam operation, and when cooled to liquid nitrogen temperatures (77°K). In 1970, Zhores Alferov, in the USSR, and Izuo Hayashi and Morton Panish of Bell Telephone Laboratories also independently developed room-temperature, continual-operation diode lasers, using the heterojunction structure.

Recent innovations



Graph showing the history of maximum laser pulse intensity throughout the past 40 years.

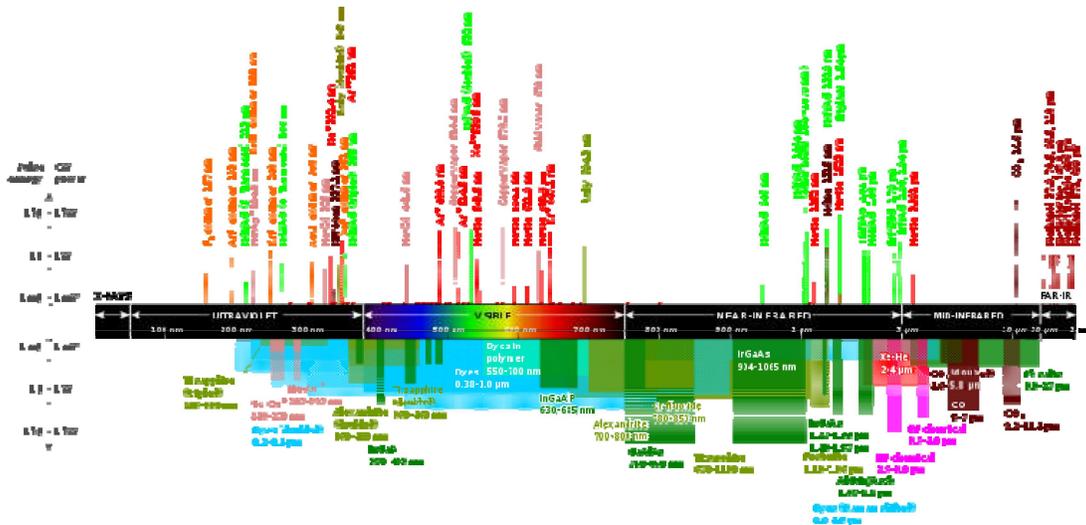
Since the early period of laser history, laser research has produced a variety of improved and specialized laser types, optimized for different performance goals, including:

- new wavelength bands
- maximum average output power
- maximum peak pulse energy
- maximum peak pulse power
- minimum output pulse duration
- maximum power efficiency
- minimum cost

and this research continues to this day.

Lasing without maintaining the medium excited into a population inversion was discovered in 1992 in sodium gas and again in 1995 in rubidium gas by various international teams. This was accomplished by using an external maser to induce "optical transparency" in the medium by introducing and destructively interfering the ground electron transitions between two paths, so that the likelihood for the ground electrons to absorb any energy has been cancelled.

Types and operating principles



Wavelengths of commercially available lasers. Laser types with distinct laser lines are shown above the wavelength bar, while below are shown lasers that can emit in a wavelength range.

Gas lasers

Following the invention of the HeNe gas laser, many other gas discharges have been found to amplify light coherently. Gas lasers using many different gases have been built and used for many purposes. The helium-neon laser (HeNe) is able to operate at a number of different wavelengths, however the vast majority are engineered to lase at 633 nm; these relatively low cost but highly coherent lasers are extremely common in optical research and educational laboratories. Commercial carbon dioxide (CO₂) lasers can emit many hundreds of watts in a single spatial mode which can be concentrated into a tiny spot. This emission is in the thermal infrared at 10.6 μm; such lasers are regularly used in industry for cutting and welding. The efficiency of a CO₂ laser is unusually high: over 10%. Argon-ion lasers can operate at a number of lasing transitions between 351 and 528.7 nm. Depending on the optical design one or more of these transitions can be lasing simultaneously; the most commonly used lines are 458 nm, 488 nm and 514.5 nm. A nitrogen transverse electrical discharge in gas at atmospheric pressure (TEA) laser is an inexpensive gas laser, often home-built by hobbyists, which produces rather incoherent UV light at 337.1 nm. Metal ion lasers are gas lasers that generate deep ultraviolet wavelengths. Helium-silver (HeAg) 224 nm and neon-copper (NeCu) 248 nm are two examples. Like all low-pressure gas lasers, the gain media of these lasers have quite narrow oscillation linewidths, less than 3 GHz (0.5 picometers), making them candidates for use in fluorescence suppressed Raman spectroscopy.

Chemical lasers

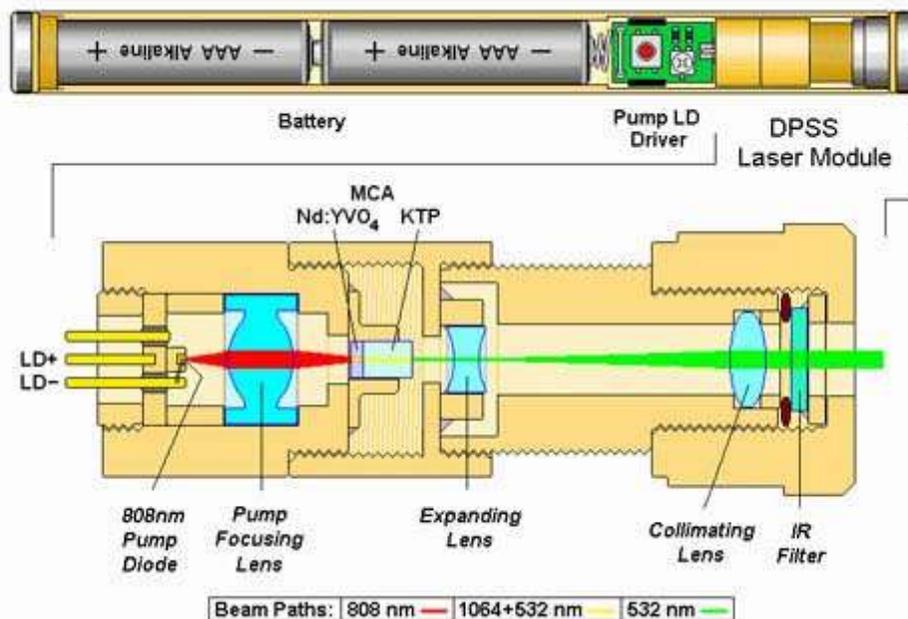
Chemical lasers are powered by a chemical reaction permitting a large amount of energy to be released quickly. Such very high power lasers are especially of interest to the military, however continuous wave chemical lasers at very high power levels, fed by

streams of gasses, have been developed and have some industrial applications. As examples, in the Hydrogen fluoride laser (2700-2900 nm) and the Deuterium fluoride laser (3800 nm) the reaction is the combination of hydrogen or deuterium gas with combustion products of ethylene in nitrogen trifluoride.

Excimer lasers

Excimer lasers are a special sort of gas laser powered by an electric discharge in which the lasing medium is an excimer, or more precisely an exciplex in existing designs. These are molecules which can only exist with one atom in an excited electronic state. Once the molecule transfers its excitation energy to a photon, therefore, its atoms are no longer bound to each other and the molecule disintegrates. This drastically reduces the population of the lower energy state thus greatly facilitating a population inversion. Excimers currently used are all noble gas compounds; noble gasses are chemically inert and can only form compounds while in an excited state. Excimer lasers typically operate at ultraviolet wavelengths with major applications including semiconductor photolithography and LASIK eye surgery. Commonly used excimer molecules include ArF (emission at 193 nm), KrCl (222 nm), KrF (248 nm), XeCl (308 nm), and XeF (351 nm). The molecular fluorine laser, emitting at 157 nm in the vacuum ultraviolet is sometimes referred to as an excimer laser, however this appears to be a misnomer inasmuch as F₂ is a stable compound.

Solid-state lasers

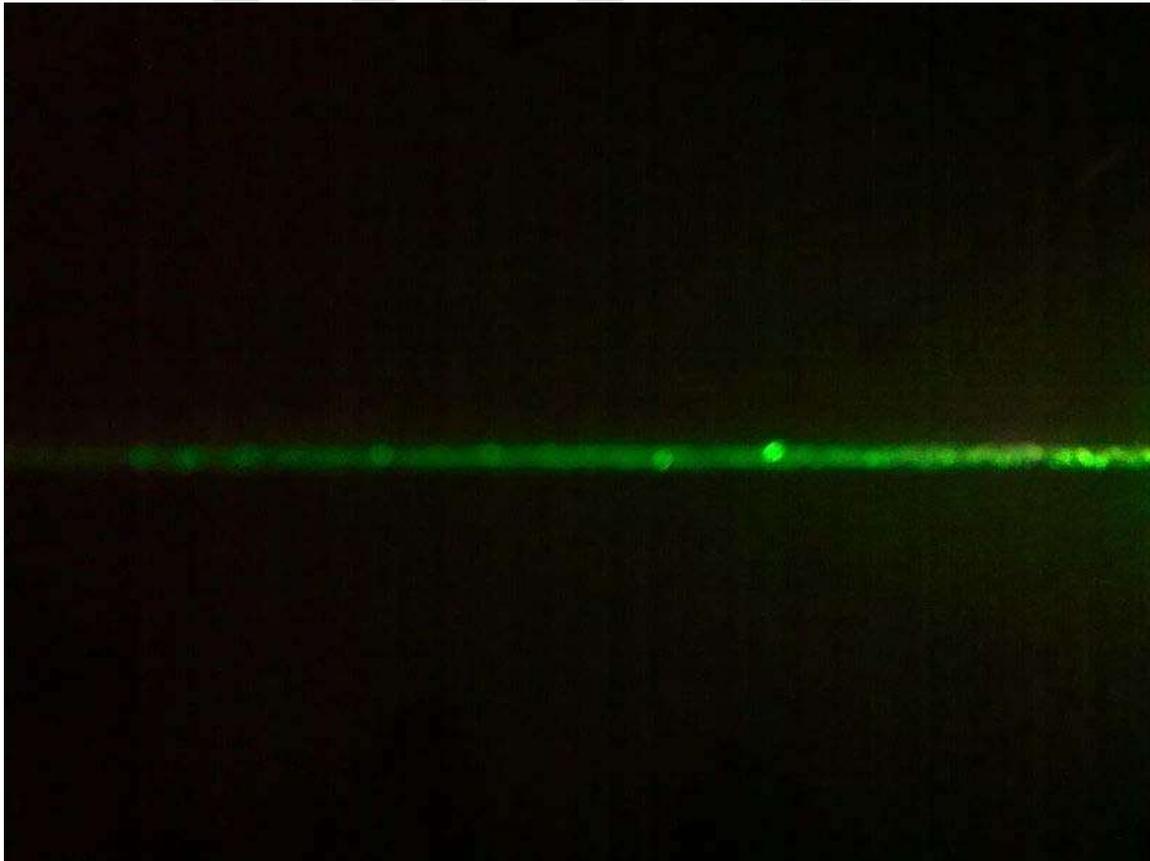


A frequency-doubled green laser pointer, showing internal construction. Two AAA cells and electronics power the laser module (lower diagram) This contains a powerful 808 nm IR diode laser that optically pumps a Nd:YVO₄ crystal inside a laser cavity. That laser

produces 1064 nm (infrared) light which is mainly confined inside the resonator. Also inside the laser cavity, however, is a non-linear KTP crystal which causes frequency doubling, resulting in green light at 532 nm. The front mirror is transparent to this visible wavelength which is then expanded and collimated using two lenses (in this particular design).

Solid-state lasers use a crystalline or glass rod which is "doped" with ions that provide the required energy states. For example, the first working laser was a ruby laser, made from ruby (chromium-doped corundum). The population inversion is actually maintained in the "dopant", such as chromium or neodymium. These materials are pumped optically using a shorter wavelength than the lasing wavelength, often from a flashtube or from another laser.

It should be noted that "solid-state" in this sense refers to a crystal or glass, but this usage is distinct from the designation of "solid-state electronics" in referring to semiconductors. Semiconductor lasers (laser diodes) are pumped electrically and are thus *not* referred to as solid-state lasers. The class of solid-state lasers would, however, properly include fiber lasers in which dopants in the glass lase under optical pumping. But in practice these are simply referred to as "fiber lasers" with "solid-state" reserved for lasers using a solid rod of such a material.



Green laser beam (Wavelength:532nm)

Neodymium is a common "dopant" in various solid-state laser crystals, including yttrium orthovanadate (Nd:YVO₄), yttrium lithium fluoride (Nd:YLF) and yttrium aluminium garnet (Nd:YAG). All these lasers can produce high powers in the infrared spectrum at 1064 nm. They are used for cutting, welding and marking of metals and other materials, and also in spectroscopy and for pumping dye lasers.

These lasers are also commonly frequency doubled, tripled or quadrupled, in so-called "diode pumped solid state" or DPSS lasers. Under second, third, or fourth harmonic generation these produce 532 nm (green, visible), 355 nm (UV) and 266 nm (UV) beams. This is the technology behind the bright laser pointers particularly at green (532 nm) and other short visible wavelengths.

Ytterbium, holmium, thulium, and erbium are other common "dopants" in solid-state lasers. Ytterbium is used in crystals such as Yb:YAG, Yb:KGW, Yb:KYW, Yb:SYS, Yb:BOYS, Yb:CaF₂, typically operating around 1020-1050 nm. They are potentially very efficient and high powered due to a small quantum defect. Extremely high powers in ultrashort pulses can be achieved with Yb:YAG. Holmium-doped YAG crystals emit at 2097 nm and form an efficient laser operating at infrared wavelengths strongly absorbed by water-bearing tissues. The Ho-YAG is usually operated in a pulsed mode, and passed through optical fiber surgical devices to resurface joints, remove rot from teeth, vaporize cancers, and pulverize kidney and gall stones.

Titanium-doped sapphire (Ti:sapphire) produces a highly tunable infrared laser, commonly used for spectroscopy. It is also notable for use as a mode-locked laser producing ultrashort pulses of extremely high peak power.

Thermal limitations in solid-state lasers arise from unconverted pump power that manifests itself as heat. This heat, when coupled with a high thermo-optic coefficient (dn/dT) can give rise to thermal lensing as well as reduced quantum efficiency. These types of issues can be overcome by another novel diode-pumped solid-state laser, the diode-pumped thin disk laser. The thermal limitations in this laser type are mitigated by using a laser medium geometry in which the thickness is much smaller than the diameter of the pump beam. This allows for a more even thermal gradient in the material. Thin disk lasers have been shown to produce up to kilowatt levels of power.

Fiber lasers

Solid-state lasers or laser amplifiers where the light is guided due to the total internal reflection in a single mode optical fiber are instead called fiber lasers. Guiding of light allows extremely long gain regions providing good cooling conditions; fibers have high surface area to volume ratio which allows efficient cooling. In addition, the fiber's waveguiding properties tend to reduce thermal distortion of the beam. Erbium and ytterbium ions are common active species in such lasers.

Quite often, the fiber laser is designed as a double-clad fiber. This type of fiber consists of a fiber core, an inner cladding and an outer cladding. The index of the three concentric

layers is chosen so that the fiber core acts as a single-mode fiber for the laser emission while the outer cladding acts as a highly multimode core for the pump laser. This lets the pump propagate a large amount of power into and through the active inner core region, while still having a high numerical aperture (NA) to have easy launching conditions.

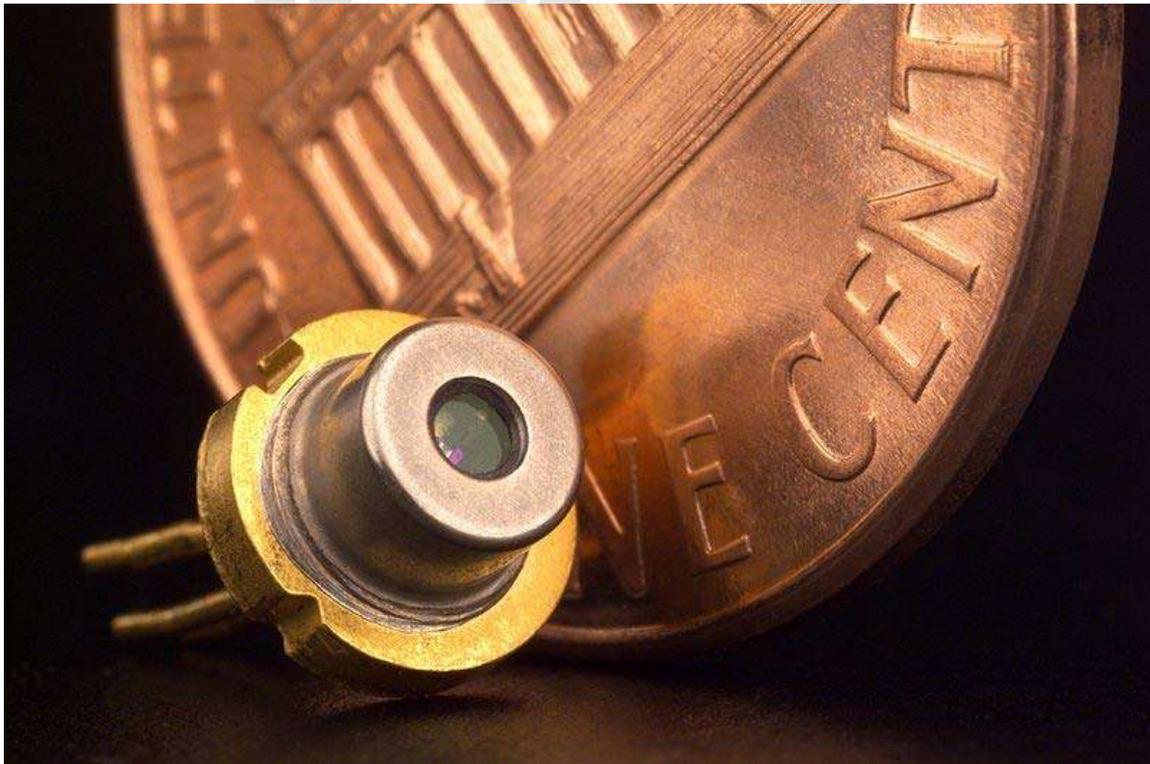
Pump light can be used more efficiently by creating a fiber disk laser, or a stack of such lasers.

Fiber lasers have a fundamental limit in that the intensity of the light in the fiber cannot be so high that optical nonlinearities induced by the local electric field strength can become dominant and prevent laser operation and/or lead to the material destruction of the fiber. This effect is called photodarkening. In bulk laser materials, the cooling is not so efficient, and it is difficult to separate the effects of photodarkening from the thermal effects, but the experiments in fibers show that the photodarkening can be attributed to the formation of long-living color centers.

Photonic crystal lasers

Photonic crystal lasers are lasers based on nano-structures that provide the mode confinement and the density of optical states (DOS) structure required for the feedback to take place. They are typical micrometre-sized and tunable on the bands of the photonic crystals.

Semiconductor lasers



A 5.6 mm 'closed can' commercial laser diode, probably from a CD or DVD player.

Semiconductor lasers are diodes which are electrically pumped. Recombination of electrons and holes created by the applied current introduces optical gain. Reflection from the ends of the crystal form an optical resonator, although the resonator can be external to the semiconductor in some designs.

Commercial laser diodes emit at wavelengths from 375 nm to 1800 nm, and wavelengths of over 3 μm have been demonstrated. Low to medium power laser diodes are used in laser printers and CD/DVD players. Laser diodes are also frequently used to optically pump other lasers with high efficiency. The highest power industrial laser diodes, with power up to 10 kW (70dBm), are used in industry for cutting and welding. External-cavity semiconductor lasers have a semiconductor active medium in a larger cavity. These devices can generate high power outputs with good beam quality, wavelength-tunable narrow-linewidth radiation, or ultrashort laser pulses.



Violet laser beam (Wavelength:405nm)

Vertical cavity surface-emitting lasers (VCSELs) are semiconductor lasers whose emission direction is perpendicular to the surface of the wafer. VCSEL devices typically have a more circular output beam than conventional laser diodes, and potentially could be

much cheaper to manufacture. As of 2005, only 850 nm VCSELs are widely available, with 1300 nm VCSELs beginning to be commercialized, and 1550 nm devices an area of research. VECSELs are external-cavity VCSELs. Quantum cascade lasers are semiconductor lasers that have an active transition between energy *sub-bands* of an electron in a structure containing several quantum wells.

The development of a silicon laser is important in the field of optical computing. Silicon is the material of choice for integrated circuits, and so electronic and silicon photonic components (such as optical interconnects) could be fabricated on the same chip. Unfortunately, silicon is a difficult lasing material to deal with, since it has certain properties which block lasing. However, recently teams have produced silicon lasers through methods such as fabricating the lasing material from silicon and other semiconductor materials, such as indium(III) phosphide or gallium(III) arsenide, materials which allow coherent light to be produced from silicon. These are called hybrid silicon laser. Another type is a Raman laser, which takes advantage of Raman scattering to produce a laser from materials such as silicon.

Dye lasers

Dye lasers use an organic dye as the gain medium. The wide gain spectrum of available dyes, or mixtures of dyes, allows these lasers to be highly tunable, or to produce very short-duration pulses (on the order of a few femtoseconds). Although these tunable lasers are mainly known in their liquid form, researchers have also demonstrated narrow-linewidth tunable emission in dispersive oscillator configurations incorporating solid-state dye gain media. In their most prevalent form these solid state dye lasers use dye-doped polymers as laser media.

Free electron lasers

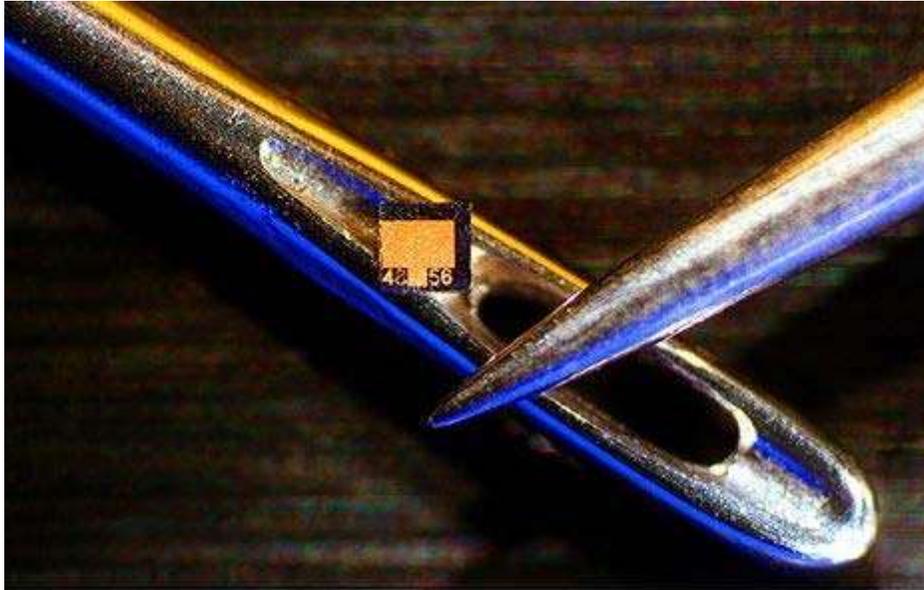
Free electron lasers, or FELs, generate coherent, high power radiation, that is widely tunable, currently ranging in wavelength from microwaves, through terahertz radiation and infrared, to the visible spectrum, to soft X-rays. They have the widest frequency range of any laser type. While FEL beams share the same optical traits as other lasers, such as coherent radiation, FEL operation is quite different. Unlike gas, liquid, or solid-state lasers, which rely on bound atomic or molecular states, FELs use a relativistic electron beam as the lasing medium, hence the term *free electron*.

Exotic laser media

In September 2007, the BBC News reported that there was speculation about the possibility of using positronium annihilation to drive a very powerful gamma ray laser. Dr. David Cassidy of the University of California, Riverside proposed that a single such laser could be used to ignite a nuclear fusion reaction, replacing the banks of hundreds of lasers currently employed in inertial confinement fusion experiments.

Space-based X-ray lasers pumped by a nuclear explosion have also been proposed as antimissile weapons. Such devices would be one-shot weapons.

Uses



Lasers range in size from microscopic diode lasers (top) with numerous applications, to football field sized neodymium glass lasers (bottom) used for inertial confinement fusion, nuclear weapons research and other high energy density physics experiments.

When lasers were invented in 1960, they were called "a solution looking for a problem". Since then, they have become ubiquitous, finding utility in thousands of highly varied applications in every section of modern society, including consumer electronics,

information technology, science, medicine, industry, law enforcement, entertainment, and the military.

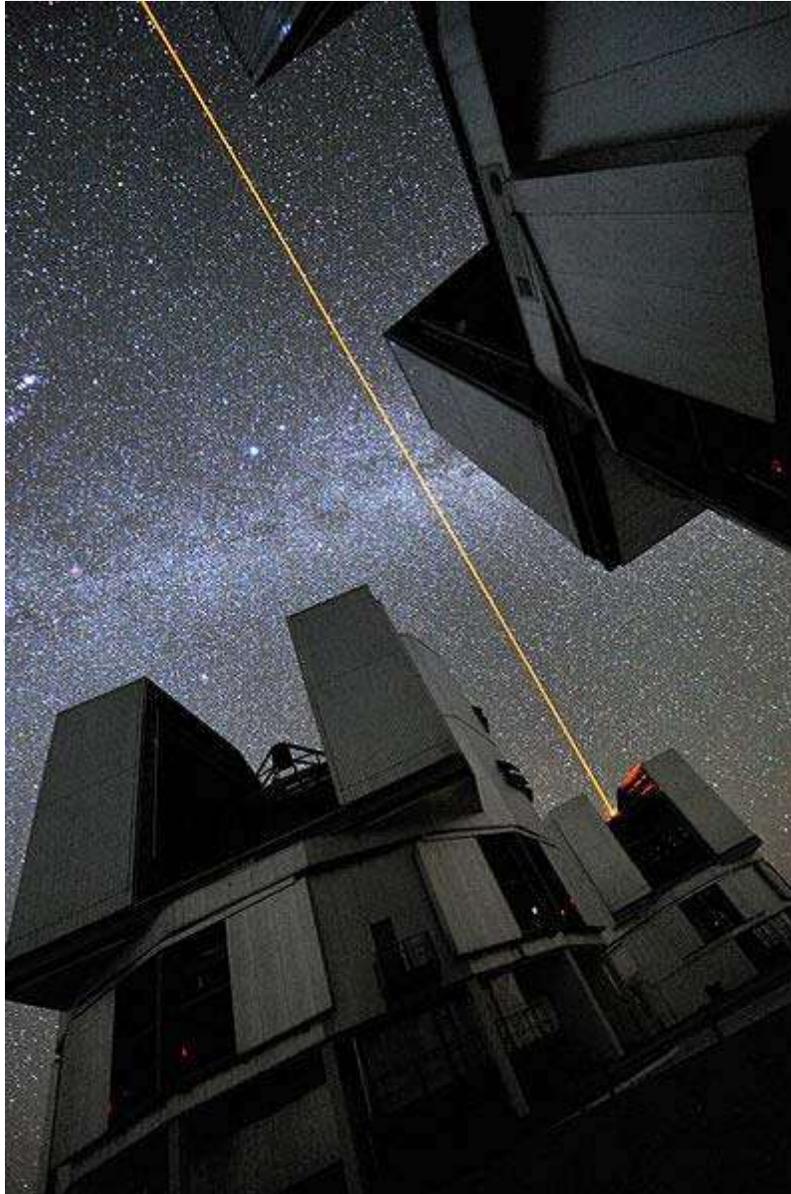
The first use of lasers in the daily lives of the general population was the supermarket barcode scanner, introduced in 1974. The laserdisc player, introduced in 1978, was the first successful consumer product to include a laser but the compact disc player was the first laser-equipped device to become common, beginning in 1982 followed shortly by laser printers.

Some other uses are:

- Medicine: Bloodless surgery, laser healing, surgical treatment, kidney stone treatment, eye treatment, dentistry
- Industry: Cutting, welding, material heat treatment, marking parts, non-contact measurement of parts
- Military: Marking targets, guiding munitions, missile defence, electro-optical countermeasures (EOCM), alternative to radar, blinding troops.
- Law enforcement: used for latent fingerprint detection in the forensic identification field
- Research: Spectroscopy, laser ablation, laser annealing, laser scattering, laser interferometry, LIDAR, laser capture microdissection, fluorescence microscopy
- Product development/commercial: laser printers, optical discs (e.g. CDs and the like), barcode scanners, thermometers, laser pointers, holograms, bubblegrams.
- Laser lighting displays: Laser light shows
- Cosmetic skin treatments: acne treatment, cellulite and striae reduction, and hair removal.

In 2004, excluding diode lasers, approximately 131,000 lasers were sold with a value of US\$2.19 billion. In the same year, approximately 733 million diode lasers, valued at \$3.20 billion, were sold.

Examples by power



Laser application in astronomical adaptive optics imaging.

Different applications need lasers with different output powers. Lasers that produce a continuous beam or a series of short pulses can be compared on the basis of their average power. Lasers that produce pulses can also be characterized based on the *peak* power of each pulse. The peak power of a pulsed laser is many orders of magnitude greater than its average power. The average output power is always less than the power consumed.

The continuous or average power required for some uses:

- 1-5 mW – laser pointers
- 5 mW – CD-ROM drive
- 5–10 mW – DVD player or DVD-ROM drive

- 100 mW – High-speed CD-RW burner
- 250 mW – Consumer DVD-R burner
- 1 W – green laser in current Holographic Versatile Disc prototype development
- 1–20 W – output of the majority of commercially available solid-state lasers used for micro machining
- 30–100 W – typical sealed CO₂ surgical lasers
- 100–3000 W – typical sealed CO₂ lasers used in industrial laser cutting
- 1 kW – Output power expected to be achieved by a prototype 1 cm diode laser bar
- 100 kW - Claimed output of a CO₂ laser being developed by Northrop Grumman for military (weapon) applications.

Examples of pulsed systems with high peak power:

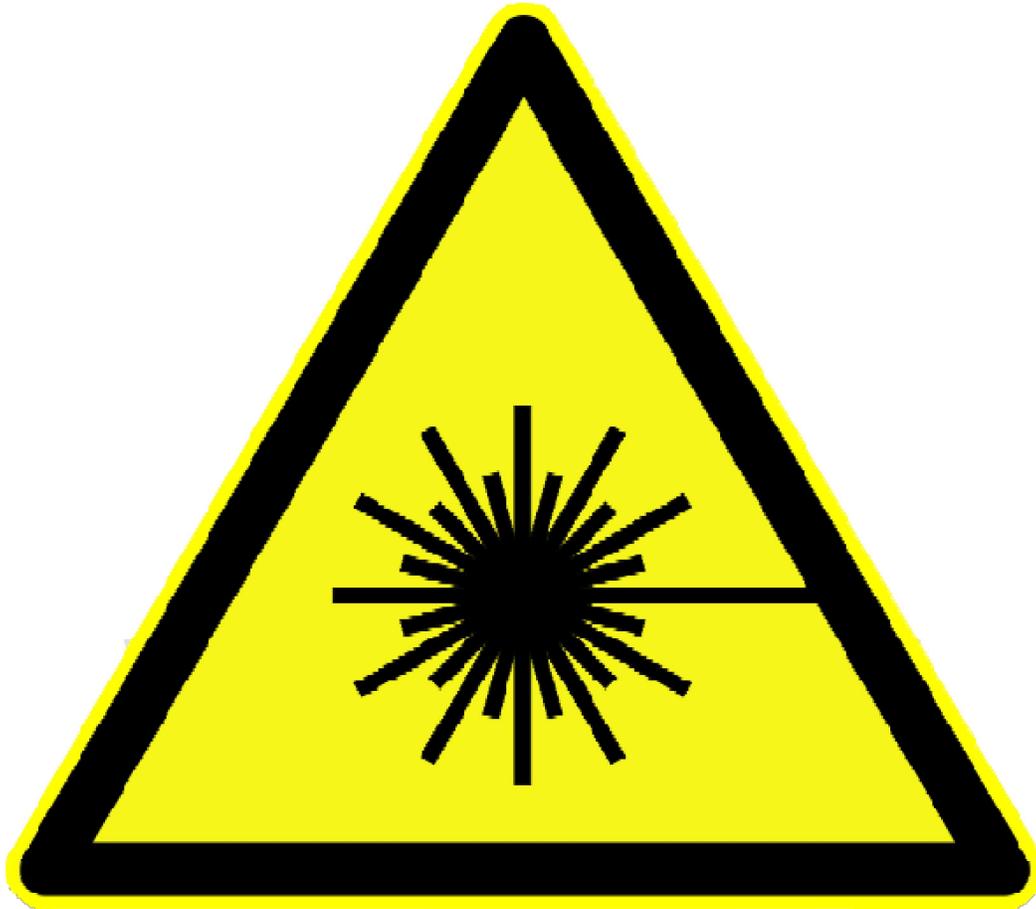
- 700 TW (700×10^{12} W) – National Ignition Facility, a 192-beam, 1.8-megajoule laser system adjoining a 10-meter-diameter target chamber.
- 1.3 PW (1.3×10^{15} W) – world's most powerful laser as of 1998, located at the Lawrence Livermore Laboratory

Hobby uses

In recent years, some hobbyists have taken interests in lasers. Lasers used by hobbyists are generally of class IIIa or IIIb, although some have made their own class IV types. However, compared to other hobbyists, laser hobbyists are far less common, due to the cost and potential dangers involved. Due to the cost of lasers, some hobbyists use inexpensive means to obtain lasers, such as salvaging laser diodes from broken DVD players (red), Blu-ray players (violet), or even higher power laser diodes from CD or DVD burners.

Hobbyists also have been taking surplus pulsed lasers from retired military applications and modifying them for pulsed holography. Pulsed Ruby and pulsed YAG lasers have been used.

Safety



Warning symbol for lasers.

Even the first laser was recognized as being potentially dangerous. Theodore Maiman characterized the first laser as having a power of one "Gillette" as it could burn through one Gillette razor blade. Today, it is accepted that even low-power lasers with only a few milliwatts of output power can be hazardous to human eyesight, when the beam from such a laser hits the eye directly or after reflection from a shiny surface. At wavelengths which the cornea and the lens can focus well, the coherence and low divergence of laser light means that it can be focused by the eye into an extremely small spot on the retina, resulting in localized burning and permanent damage in seconds or even less time.

Lasers are usually labeled with a safety class number, which identifies how dangerous the laser is:

- Class I/1 is inherently safe, usually because the light is contained in an enclosure, for example in CD players.
- Class II/2 is safe during normal use; the blink reflex of the eye will prevent damage. Usually up to 1 mW power, for example laser pointers.
- Class IIIa/3R lasers are usually up to 5 mW and involve a small risk of eye damage within the time of the blink reflex. Staring into such a beam for several seconds is likely to cause damage to a spot on the retina.

- Class IIIb/3B can cause immediate eye damage upon exposure.
- Class IV/4 lasers can burn skin, and in some cases, even scattered light can cause eye and/or skin damage. Many industrial and scientific lasers are in this class.

The indicated powers are for visible-light, continuous-wave lasers. For pulsed lasers and invisible wavelengths, other power limits apply. People working with class 3B and class 4 lasers can protect their eyes with safety goggles which are designed to absorb light of a particular wavelength.

Certain infrared lasers with wavelengths beyond about 1.4 micrometres are often referred to as being "eye-safe". This is because the intrinsic molecular vibrations of water molecules very strongly absorb light in this part of the spectrum, and thus a laser beam at these wavelengths is attenuated so completely as it passes through the eye's cornea that no light remains to be focused by the lens onto the retina. The label "eye-safe" can be misleading, however, as it only applies to relatively low power continuous wave beams; any high power or Q-switched laser at these wavelengths can burn the cornea, causing severe eye damage.

As weapons

Laser beams are famously employed as weapon systems in science fiction, but actual laser weapons are still in the experimental stage. The general idea of laser-beam weaponry is to hit a target with a train of brief pulses of light. The rapid evaporation and expansion of the surface causes shockwaves that damage the target. The power needed to project a high-powered laser beam of this kind is beyond the limit of current mobile power technology thus favoring chemically powered gas dynamic lasers.

Lasers of all but the lowest powers can potentially be used as incapacitating weapons, through their ability to produce temporary or permanent vision loss in varying degrees when aimed at the eyes. The degree, character, and duration of vision impairment caused by eye exposure to laser light varies with the power of the laser, the wavelength(s), the collimation of the beam, the exact orientation of the beam, and the duration of exposure. Lasers of even a fraction of a watt in power can produce immediate, permanent vision loss under certain conditions, making such lasers potential non-lethal but incapacitating weapons. The extreme handicap that laser-induced blindness represents makes the use of lasers even as non-lethal weapons morally controversial, and weapons designed to cause blindness have been banned by the Protocol on Blinding Laser Weapons. The U.S. Air Force is currently working on the YAL-1 airborne laser, mounted in a Boeing 747, to shoot down enemy ballistic missiles over enemy territory.

In the field of aviation, the hazards of exposure to ground-based lasers deliberately aimed at pilots have grown to the extent that aviation authorities have special procedures to deal with such hazards.

On March 18, 2009 Northrop Grumman claimed that its engineers in Redondo Beach had successfully built and tested an electrically powered CO₂ laser capable of producing a

100-kilowatt beam, powerful enough to destroy an airplane or a tank. According to Brian Strickland, manager for the United States Army's Joint High Power Solid State Laser program, an electrically powered laser is capable of being mounted in an aircraft, ship, or other vehicle because it requires much less space for its supporting equipment than a chemical laser. However the source of such a large electrical power in a mobile application remains unclear.

Fictional predictions

Before stimulated emission was discovered, novelists used to describe machines that we can identify as "lasers".

- A laser-like device was described in Alexey Tolstoy's science fiction novel *The Hyperboloid of Engineer Garin* in 1927.
- Mikhail Bulgakov exaggerated the biological effect (laser bio stimulation) of intensive red light in his science fiction novel *Fatal Eggs* (1925), without any reasonable description of the source of this red light. (In that novel, the red light first appears occasionally from the illuminating system of an advanced microscope; then the protagonist Prof. Persikov arranges the special set-up for generation of the red light.)

Electromagnetic Pulse

The term **electromagnetic pulse** (sometimes abbreviated **EMP**) is a burst of electromagnetic radiation that results from an explosion (usually from the detonation of a nuclear weapon) and/or a suddenly fluctuating magnetic field. The resulting rapidly changing electric fields or magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges.

In military terminology, a nuclear bomb detonated hundreds of kilometers above the Earth's surface is known as a high-altitude electromagnetic pulse (**HEMP**) device. Nuclear electromagnetic pulse has three distinct time components that result from different physical phenomena. Effects of a HEMP device depend on a very large number of factors, including the altitude of the detonation, energy yield, gamma ray output, interactions with the Earth's magnetic field, and electromagnetic shielding of targets.

History

The fact that an electromagnetic pulse is produced by a nuclear explosion was known since the earliest days of nuclear weapons testing, but the magnitude of the EMP and the significance of its effects were not realized for some time.

During the first United States nuclear test on 16 July 1945, electronic equipment was shielded due to Enrico Fermi's expectation of an electromagnetic pulse from the detonation. The official technical history for that first nuclear test states, "All signal lines were completely shielded, in many cases doubly shielded. In spite of this many records were lost because of spurious pickup at the time of the explosion that paralyzed the recording equipment." During British nuclear testing in 1952–1953 there were instrumentation failures that were attributed to "radioflash," which was then the British term for EMP.

The high altitude nuclear tests of 1962, as described below, increased awareness of EMP beyond the original small population of nuclear weapons scientists and engineers. The larger scientific community became aware of the significance of the EMP problem after a series of three articles were published about nuclear electromagnetic pulse in 1981 by William J. Broad in the weekly publication *Science*.

Starfish Prime

In July 1962, a 1.44 megaton (6.0 PJ) United States nuclear test in space, 400 kilometres (250 mi) above the mid-Pacific Ocean, called the Starfish Prime test, demonstrated to nuclear scientists that the magnitude and effects of a high altitude nuclear explosion were much larger than had been previously calculated. Starfish Prime also made those effects known to the public by causing electrical damage in Hawaii, about 1,445 kilometres (898 mi) away from the detonation point, knocking out about 300 streetlights, setting off numerous burglar alarms and damaging a telephone company microwave link.

Starfish Prime was the first successful test in the series of United States high-altitude nuclear tests in 1962 known as Operation Fishbowl. The subsequent Operation Fishbowl tests gathered more data on the high-altitude EMP phenomenon.

The *Bluegill Triple Prime* and *Kingfish* high-altitude nuclear tests of October and November 1962 in Operation Fishbowl finally provided electromagnetic pulse data that was clear enough to enable physicists to accurately identify the physical mechanisms that were producing the electromagnetic pulses.

The EMP damage of the Starfish Prime test was quickly repaired because of the ruggedness (compared to today) of the electrical and electronic infrastructure of Hawaii in 1962. Realization of the potential impacts of EMP became more apparent to some scientists and engineers during the 1970s as more sensitive solid-state electronics began to come into widespread use.

The relatively small magnitude of the Starfish Prime EMP in Hawaii (about 5600 volts/metre) and the relatively small amount of damage done (for example, only 1 to 3 percent of streetlights extinguished) led some scientists to believe, in the early days of EMP research, that the problem might not be as significant as was later realized. Newer calculations showed that if the Starfish Prime warhead had been detonated over the northern continental United States, the magnitude of the EMP would have been much larger (22 to 30 kilovolts/metre) because of the greater strength of the Earth's magnetic field over the United States, as well as the different orientation of the Earth's magnetic field at high latitudes. These new calculations, combined with the accelerating reliance on EMP-sensitive microelectronics, heightened awareness that the EMP threat could be a very significant problem.

Soviet Test 184

In 1962, the Soviet Union also performed a series of three EMP-producing nuclear tests in space over Kazakhstan, which were the last in the series called "The K Project". Although these weapons were much smaller (300 kilotons or 1.3 PJ) than the Starfish Prime test, since those tests were done over a populated large land mass (and also at a location where the Earth's magnetic field was greater), the damage caused by the resulting EMP was reportedly much greater than in the Starfish Prime nuclear test. The geomagnetic storm-like E3 pulse (from the test designated as "Test 184") even induced

an electric current surge in a long underground power line that caused a fire in the power plant in the city of Karaganda. After the collapse of the Soviet Union, the level of this damage was communicated informally to scientists in the United States. Formal documentation of some of the EMP damage in Kazakhstan exists but is still sparse in the open scientific literature.

Non-nuclear history

The concept of the explosively pumped flux compression generator for generating a non-nuclear electromagnetic pulse was conceived as early as 1951 by Andrei Sakharov in the Soviet Union, but nations have usually kept their most recent work on non-nuclear EMP highly classified until the technology was old enough for similar ideas to be conceived by physicists in other nations.

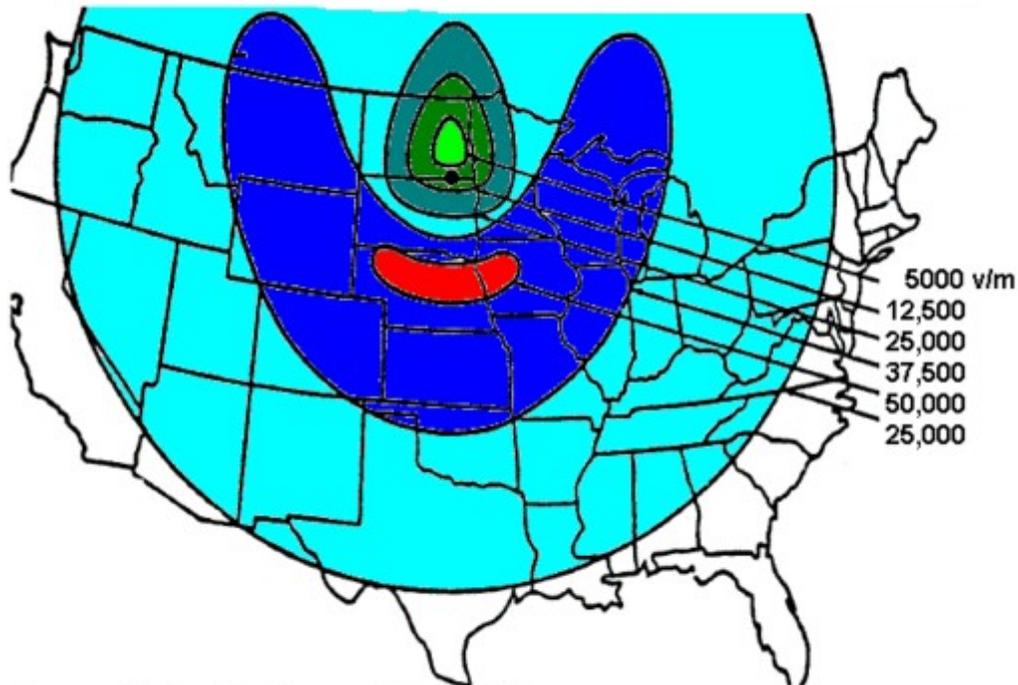
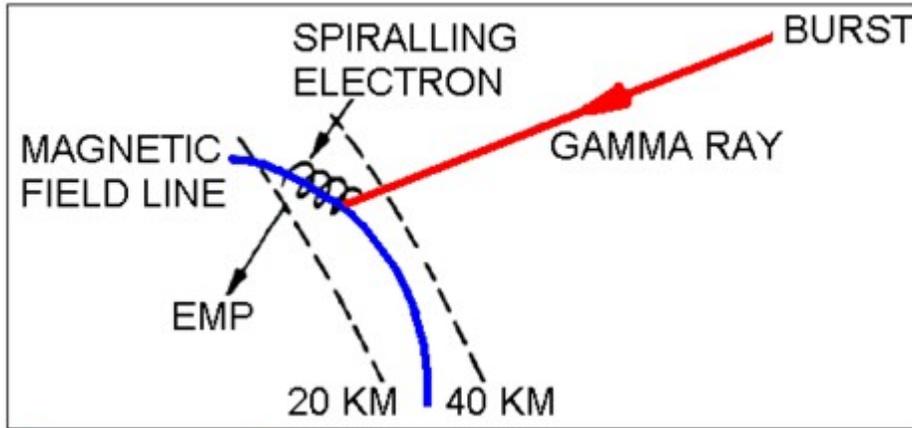
Characteristics of nuclear EMP

The case of a **nuclear electromagnetic pulse** differs from other kinds of electromagnetic pulse (EMP) in being a complex electromagnetic multi-pulse. The complex multi-pulse is usually described in terms of three components, and these three components have been defined as such by the international standards commission called the International Electrotechnical Commission (IEC).

The three components of nuclear EMP, as defined by the IEC, are called **E1**, **E2** and **E3**.

E1

The **E1** pulse is the very fast component of nuclear EMP. The **E1** component is a very brief but intense electromagnetic field that can quickly induce very high voltages in electrical conductors. The **E1** component causes most of its damage by causing electrical breakdown voltages to be exceeded. **E1** is the component that can destroy computers and communications equipment and it changes too fast for ordinary lightning protectors to provide effective protection against it.



Source: Nuclear Environment Survivability, U. S. Army, report AD-A278230 (1994)

The mechanism for a 400 km high altitude burst EMP: gamma rays hit the atmosphere between 20–40 km altitude, ejecting electrons which are then deflected sideways by the Earth's magnetic field. This makes the electrons radiate EMP over a massive area. Because of the curvature and downward tilt of Earth's magnetic field over the USA, the maximum EMP occurs south of the detonation and the minimum occurs to the north.

The E1 component is produced when gamma radiation from the nuclear detonation knocks electrons out of the atoms in the upper atmosphere. The electrons begin to travel in a generally downward direction at relativistic speeds (more than 90 percent of the speed of light). In the absence of a magnetic field, this would produce a large pulse of electric current vertically in the upper atmosphere over the entire affected area. The Earth's magnetic field acts on these electrons to change the direction of electron flow to a right angle to the geomagnetic field. This interaction of the Earth's magnetic field and the

downward electron flow produces a very large, but very brief, electromagnetic pulse over the affected area.

Physicist Conrad Longmire has given numerical values for a typical case of the E1 pulse produced by a second generation nuclear weapon such as those used in high altitude tests of Operation Fishbowl in 1962. According to Longmire, the typical gamma rays given off by the weapon have an energy of about 2 MEV (million electron volts). When these gamma rays collide with atoms in the mid-stratosphere, the gamma rays knock out electrons. This is known as the Compton effect, and the resulting electrons produce an electric current that is known as the Compton current. The gamma rays transfer about half of their energy to the electrons, so these initial electrons have an energy of about 1 MEV. This causes the electrons to begin to travel in a generally downward direction at about 94 percent of the speed of light. Relativistic effects cause the mass of these high energy electrons to increase to about 3 times their normal rest mass.

If there were no geomagnetic field, and no additional atoms in the lower atmosphere for additional collisions, the electrons would continue to travel downward with an average current density in the stratosphere of about 48 amperes per square metre.

Because of the downward tilt of the Earth's magnetic field at high latitudes, the area of peak field strength is a U-shaped region to the equatorial side of the nuclear detonation. As shown in the diagram at the right, for nuclear detonations over the continental United States, this U-shaped region is south of the detonation point. Near the equator, where the Earth's magnetic field is more nearly horizontal, the E1 field strength is more nearly symmetrical around the burst location.

The Earth's magnetic field quickly deflects the electrons at right angles to the geomagnetic field, and the extent of the deflection depends upon the strength of the magnetic field. At geomagnetic field strengths typical of the central United States, central Europe or Australia, these initial electrons spiral around the magnetic field lines in a circle with a typical radius of about 85 metres (about 280 feet). These initial electrons are stopped by collisions with other air molecules at a average distance of about 170 metres (a little less than 580 feet). This means that most of the electrons are stopped by collisions with air molecules before they can complete one full circle of its spiral around the Earth's magnetic field lines.

This interaction of the very rapidly moving negatively charged electrons with the magnetic field radiates a pulse of electromagnetic energy. The pulse typically rises to its peak value in about 5 nanoseconds. The magnitude of this pulse typically decays to half of its peak value within 200 nanoseconds. (By the IEC definition, this E1 pulse is ended at one microsecond (1000 nanoseconds) after it begins.) This process occurs simultaneously with about 10^{25} other electrons.

There are a number of secondary collisions which cause the subsequent electrons to lose energy before they reach ground level. The electrons generated by these subsequent

collisions have such reduced energy that they do not contribute significantly to the E1 pulse.

These 2 MEV gamma rays will normally produce an E1 pulse near ground level at moderately high latitudes that peaks at about 50,000 volts per metre. This is a peak power density of 6.6 megawatts per square metre.

The process of the gamma rays knocking electrons out of the atoms in the mid-stratosphere causes this region of the atmosphere to become an electrical conductor due to ionization, a process which blocks the production of further electromagnetic signals and causes the field strength to saturate at about 50,000 volts per metre. The strength of the E1 pulse depends upon the number and intensity of the gamma rays produced by the weapon and upon the rapidity of the gamma ray burst from the weapon. The strength of the E1 pulse is also somewhat dependent upon the altitude of the detonation.

There are reports of "super-EMP" nuclear weapons that are able to overcome the 50,000 volt per metre limit by the very nearly instantaneous release of a burst of gamma radiation of much higher energy levels than are known to be produced by second generation nuclear weapons. The construction details of these weapons are classified, and therefore cannot be confirmed by scientists in the open scientific literature.

E2

The **E2** component is generated by scattered gamma rays and inelastic gammas produced by weapon neutrons. This E2 component is an "intermediate time" pulse that, by the IEC definition, lasts from about 1 microsecond to 1 second after the beginning of the electromagnetic pulse. The E2 component of the pulse has many similarities to the electromagnetic pulses produced by lightning, although the electromagnetic pulse induced by a nearby lightning strike may be considerably larger than the E2 component of a nuclear EMP. Because of the similarities to lightning-caused pulses and the widespread use of lightning protection technology, the E2 pulse is generally considered to be the easiest to protect against.

According to the United States EMP Commission, the main potential problem with the E2 component is the fact that it immediately follows the E1 component, which may have damaged the devices that would normally protect against E2.

According to the EMP Commission Executive Report of 2004, "In general, it would not be an issue for critical infrastructure systems since they have existing protective measures for defense against occasional lightning strikes. The most significant risk is synergistic, because the E2 component follows a small fraction of a second after the first component's insult, which has the ability to impair or destroy many protective and control features. The energy associated with the second component thus may be allowed to pass into and damage systems."

E3

The **E3** component is very different from the other two major components of nuclear EMP. The E3 component of the pulse is a very slow pulse, lasting tens to hundreds of seconds, that is caused by the nuclear detonation heaving the Earth's magnetic field out of the way, followed by the restoration of the magnetic field to its natural place. The E3 component has similarities to a geomagnetic storm caused by a very severe solar flare. Like a geomagnetic storm, E3 can produce geomagnetically induced currents in long electrical conductors, which can then damage components such as power line transformers.

Because of the similarity between solar-induced geomagnetic storms and nuclear E3, it has become common to refer to solar-induced geomagnetic storms as "solar EMP." At ground level, however, "solar EMP" is not known to produce an E1 or E2 component.

Practical considerations for nuclear EMP

Older, vacuum tube (valve) based equipment is generally much less vulnerable to EMP than newer solid state equipment. Soviet Cold War-era military aircraft often had avionics based on vacuum tubes due both to limitations in Soviet solid-state capabilities and a belief that the vacuum-tube gear would survive better.

Although vacuum tubes are far more resistant to EMP than solid state devices, other components in vacuum tube circuitry can be damaged by EMP. Vacuum tube equipment actually was damaged in 1962 nuclear EMP testing. Also, the solid state PRC-77 VHF manpackable 2-way radio survived extensive EMP testing. The earlier PRC-25, nearly identical except for a vacuum tube final amplification stage, had been tested in EMP simulators but was not certified to remain fully functional.

Many nuclear detonations have taken place using bombs dropped by aircraft. The B-29 aircraft that delivered the nuclear weapons at Hiroshima and Nagasaki did not lose power due to damage to their electrical or electronic systems. This is simply because electrons (ejected from the air by gamma rays) are stopped quickly in normal air for bursts below roughly 10 km (about 6 miles), so they do not get a chance to be significantly deflected by the Earth's magnetic field (the deflection causes the powerful EMP seen in high altitude bursts), thus the limited use of smaller burst altitudes for widespread EMP.

If the aircraft carrying the Hiroshima and Nagasaki bombs had been within the intense nuclear radiation zone when the bombs exploded over those cities, then they would have suffered effects from the charge separation (radial) EMP. But this only occurs within the severe blast radius for detonations below about 10 km altitude.

During nuclear tests in 1962, EMP disruptions were suffered aboard KC-135 photographic aircraft flying 300 km (190 mi) from the 410 kt (1,700 TJ) *Bluegill Triple Prime* and 410 kt (1,700 TJ) *Kingfish* detonations (48 and 95 km (30 and 59 mi) burst altitude, respectively) but the vital aircraft electronics were far less sophisticated than today and the aircraft were able to land safely.

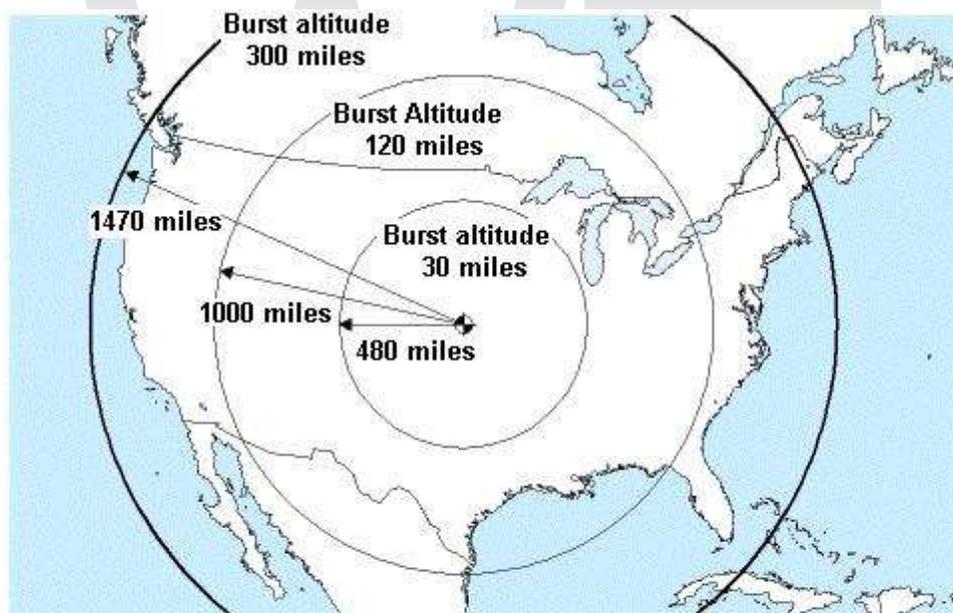
Generation of nuclear EMP

Several major factors control the effectiveness of a nuclear EMP weapon. These are:

1. The altitude of the weapon when detonated;
2. The yield and construction details of the weapon;
3. The distance from the weapon when detonated;
4. Geographical depth or intervening geographical features;
5. The local strength of the Earth's magnetic field.

Beyond a certain altitude a nuclear weapon will not produce any EMP, as the gamma rays will have had sufficient distance to disperse. In deep space or on worlds with no magnetic field (the moon or Mars for example) there will be little or no EMP. This has implications for certain kinds of nuclear rocket engines, such as Project Orion.

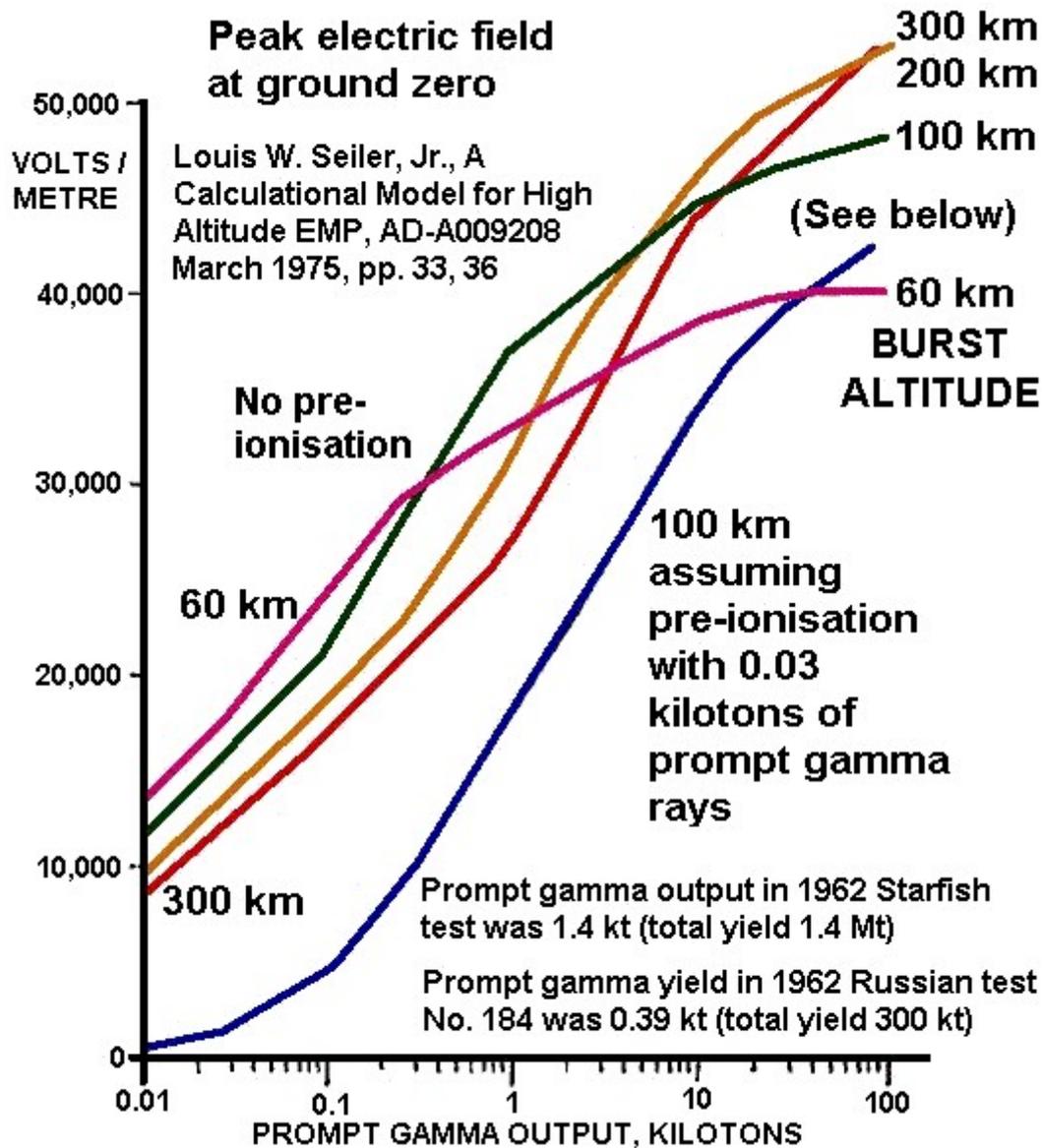
Weapon altitude



EMP AREA BY BURSTS AT 30, 120 and 300 MILES

Gary Smith, "Electromagnetic Pulse Threats", testimony to House National Security Committee on July 16, 1997

How the area affected depends on the burst altitude.



How the peak EMP on the ground varies with the weapon yield and burst altitude. The yield here is the prompt gamma ray output measured in kilotons. This varies from 0.115–0.5% of the total weapon yield, depending on weapon design. The 1.4 Mt total yield 1962 Starfish Prime test had a gamma output of 0.1%, hence 1.4 kt of prompt gamma rays. (The **blue** 'pre-ionisation' curve applies to certain types of thermonuclear weapon, where gamma and x-rays from the primary fission stage ionise the atmosphere and make it electrically conductive before the main pulse from the thermonuclear stage. The pre-ionisation in some situations can literally short out part of the final EMP, by allowing a conduction current to immediately oppose the Compton current of electrons.)

According to an internet primer published by the Federation of American Scientists

A high-altitude nuclear detonation produces an immediate flux of gamma rays from the nuclear reactions within the device. These photons in turn produce high energy free electrons by Compton scattering at altitudes between (roughly) 20 and 40 km. These electrons are then trapped in the Earth's magnetic field, giving rise to an oscillating electric current. This current is asymmetric in general and gives rise to a rapidly rising radiated electromagnetic field called an electromagnetic pulse (EMP). Because the electrons are trapped essentially simultaneously, a very large electromagnetic source radiates coherently. The pulse can easily span continent-sized areas, and this radiation can affect systems on land, sea, and air. The first recorded EMP incident accompanied a high-altitude nuclear test over the South Pacific and resulted in power system failures as far away as Hawaii. A large device detonated at 400–500 km (250 to 312 miles) over Kansas would affect all of the continental U.S. The signal from such an event extends to the visual horizon as seen from the burst point.

Thus, for equipment to be affected, the weapon needs to be above the visual horizon. Because of the nature of the pulse as a large, high powered, noisy spike, it is doubtful that there would be much protection if the explosion were seen in the sky just below the tops of hills or mountains.

The altitude indicated above is greater than that of the International Space Station and many low Earth orbit satellites. Large weapons could have a dramatic impact on satellite operations and communications such as occurred during the 1962 tests. The damaging effects on orbiting satellites are usually due to other factors besides EMP. In the Starfish Prime nuclear test, most satellite damage was due to damage to the solar panels from satellites passing through radiation belts created by the high altitude nuclear explosion.

Weapon yield

Typical nuclear weapon yields used during Cold War planning for EMP attacks were in the range of 1 to 10 megatons (4.2 to 42 PJ) This is roughly 50 to 500 times the sizes of the weapons the United States used in Japan at Hiroshima and Nagasaki. Physicists have testified at United States Congressional hearings, however, that weapons with yields of 10 kilotons (42 TJ) or less can produce a very large EMP.

The EMP at a fixed distance from a nuclear weapon does not depend directly on the yield but at most only increases as the square root of the yield. This means that although a 10 kiloton weapon has only 0.7% of the total energy release of the 1.44-megaton Starfish Prime test, the EMP will be at least 8% as powerful. Since the E1 component of nuclear EMP depends on the prompt gamma ray output, which was only 0.1% of yield in Starfish Prime but can be 0.5% of yield in pure fission weapons of low yield, a 10 kiloton bomb can easily be $5 \times 8\% = 40\%$ as powerful as the 1.44 megaton Starfish Prime at producing EMP.

The total prompt gamma ray energy in a fission explosion is 3.5% of the yield, but in a 10 kiloton detonation the high explosive around the bomb core absorbs about 85% of the

prompt gamma rays, so the output is only about 0.5% of the yield in kilotons. In the thermonuclear Starfish Prime the fission yield was less than 100% to begin with, and then the thicker outer casing absorbed about 95% of the prompt gamma rays from the pusher around the fusion stage. Thermonuclear weapons are also less efficient at producing EMP because the first stage can pre-ionize the air which becomes conductive and hence rapidly shorts out the electron Compton currents generated by the final, larger yield thermonuclear stage. Hence, small pure fission weapons with thin cases are far more efficient at causing EMP than most megaton bombs.

This analysis, however, only applies to the fast E1 and E2 components of nuclear EMP. The geomagnetic storm-like E3 component of nuclear EMP is more closely proportional to the total energy yield of the weapon.

Weapon distance

A unique and important aspect of **nuclear** EMP is that all of the components of the electromagnetic pulse are generated **outside** of the weapon. The important E1 component is generated by interaction with the electrons in the upper atmosphere that are hit by gamma radiation from the weapon — and the subsequent effects upon those electrons by the Earth's magnetic field.

For high-altitude nuclear explosions, this means that much of the EMP is actually generated at a large distance from the detonation (where the gamma radiation from the explosion hits the upper atmosphere). This causes the electric field from the EMP to be remarkably uniform over the large area affected.

According to the standard reference text on nuclear weapons effects published by the U.S. Department of Defense, "The peak electric field (and its amplitude) at the Earth's surface from a high-altitude burst will depend upon the explosion yield, the height of the burst, the location of the observer, and the orientation with respect to the geomagnetic field. As a general rule, however, the field strength may be expected to be tens of kilovolts per meter over most of the area receiving the EMP radiation."

The same reference book also states that, "... over most of the area affected by the EMP the electric field strength on the ground would exceed $0.5E_{\max}$. For yields of less than a few hundred kilotons, this would not necessarily be true because the field strength at the Earth's tangent could be substantially less than $0.5E_{\max}$."

(E_{\max} refers to the maximum electric field strength in the affected area.)

In other words, the electric field strength in the entire area that is affected by the EMP will be fairly uniform for weapons with a large gamma ray output; but for much smaller weapons, the electric field may fall off at a comparatively faster rate at large distances from the detonation point.

It is the **peak electric field** of the EMP that determines the **peak voltage** induced in equipment and other electrical conductors on the ground, and most of the damage is determined by induced voltages.

For nuclear detonations within the atmosphere, the situation is more complex. Within the range of gamma ray deposition, simple laws no longer hold as the air is ionised and there are other EMP effects, such as a radial electric field due to the separation of Compton electrons from air molecules, together with other complex phenomena. For a surface burst, absorption of gamma rays by air would limit the range of gamma ray deposition to approximately 10 miles, while for a burst in the lower-density air at high altitudes, the range of deposition would be far greater.

Non-nuclear electromagnetic pulse

Non-nuclear electromagnetic pulse (NNEMP) is an electromagnetic pulse generated without use of nuclear weapons. There are a number of devices that can achieve this objective, ranging from a large low-inductance capacitor bank discharged into a single-loop antenna or a microwave generator to an explosively pumped flux compression generator. To achieve the frequency characteristics of the pulse needed for optimal coupling into the target, wave-shaping circuits and/or microwave generators are added between the pulse source and the antenna. A vacuum tube particularly suitable for microwave conversion of high energy pulses is the vircator.

NNEMP generators can be carried as a payload of bombs and cruise missiles, allowing construction of electromagnetic bombs with diminished mechanical, thermal and ionizing radiation effects and without the political consequences of deploying nuclear weapons.

The range of NNEMP weapons (non-nuclear electromagnetic bombs) is severely limited compared to nuclear EMP. This is because nearly all NNEMP devices used as weapons require chemical explosives as their initial energy source, but nuclear explosives have an energy yield on the order of one million times that of chemical explosives of similar weight. In addition to the large difference in the energy density of the initial energy source, the electromagnetic pulse from NNEMP weapons must come from within the weapon itself, while nuclear weapons generate EMP as a secondary effect, often at great distances from the detonation. These facts severely limit the range of NNEMP weapons as compared to their nuclear counterparts, but allow for more surgical target discrimination. The effect of small e-bombs has proven to be sufficient for certain terrorist or military operations. Examples of such operations include the destruction of certain fragile electronic control systems of the type critical to the operation of many ground vehicles and aircraft.



A right front view of a Boeing E-4 National Airborne Operations Center aircraft on the electromagnetic pulse (EMP) simulator (HAGII-C) for testing.



USS *Estocin* (FFG-15) moored near the Electro Magnetic Pulse Radiation Environmental Simulator for Ships I (EMPRESS I) facility (antennae at top of image).

NNEMP generators also include large structures built to generate EMP for testing of electronics to determine how well it survives EMP. In addition, the use of ultra-wideband radars can generate EMP in areas immediately adjacent to the radar; this phenomenon is only partly understood.

Information about the EMP simulators used by the United States during the latter part of the Cold War, along with more general information about electromagnetic pulse, are now in papers under the care of the SUMMA Foundation, which is now hosted at the University of New Mexico.

The SUMMA Foundation web site includes documentation about the huge wooden Trestle simulator in New Mexico, which was the world's largest EMP simulator. Nearly all of these large EMP simulators used a specialized version of a Marx generator. The SUMMA Foundation now has a 44-minute documentary movie on its web site called "TRESTLE: Landmark of the Cold War".

Many large EMP simulators were also built in the Soviet Union, as well as in the United Kingdom, France, Germany, The Netherlands, Switzerland and Italy.

Post-Cold War nuclear EMP attack scenarios

The United States military services have developed, and in some cases have published, a number of hypothetical EMP attack scenarios.

The United States EMP Commission was authorized by the United States Congress in Fiscal Year 2001, and re-authorized in Fiscal Year 2006. The commission is formally known as the **Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack**.

The United States EMP Commission has brought together a group of notable scientists and technologists to compile several reports. In 2008, the EMP Commission released the **Critical National Infrastructures Report**. This report describes, in as much detail as practical, the likely consequences of a nuclear EMP on civilian infrastructures. Although this report was directed specifically toward the United States, most of the information can obviously be generalized to the civilian infrastructure of other industrialized countries.

The 2008 report was a followup to a more generalized report issued by the commission in 2004.

In written testimony delivered to the United States Senate in 2005, an EMP Commission staff member reported:

The EMP Commission sponsored a worldwide survey of foreign scientific and military literature to evaluate the knowledge, and possibly the intentions, of foreign states with respect to electromagnetic pulse (EMP) attack. The survey found that the physics of EMP phenomenon and the military potential of EMP attack are widely understood in the international community, as reflected in official and unofficial writings and statements. The survey of open sources over the past decade finds that knowledge about EMP and EMP attack is evidenced in at least Britain, France, Germany, Israel, Egypt, Taiwan, Sweden, Cuba, India, Pakistan, Iraq under Saddam Hussein, Iran, North Korea, China and Russia.

...

Many foreign analysts—particularly in Iran, North Korea, China, and Russia—view the United States as a potential aggressor that would be willing to use its entire panoply of weapons, including nuclear weapons, in a first strike. They perceive the United States as having contingency plans to make a nuclear EMP attack, and as being willing to execute those plans under a broad range of circumstances. Russian and Chinese military scientists in open source writings describe the basic principles of nuclear weapons designed specifically to generate an enhanced-EMP effect, that they term "Super-EMP" weapons. "Super-EMP" weapons, according to these foreign open source writings, can destroy even the best protected U.S. military and civilian electronic systems.

Clarification of common misconceptions

In non-technical writings about nuclear EMP, both in print and on the Internet, some common misconceptions about EMP are nearly always found. These widely-repeated misconceptions have led to a very considerable amount of confusion about the subject. In 2010, a technical report written for a United States government laboratory, Oak Ridge National Laboratory, even included a brief section addressing some of those EMP myths.

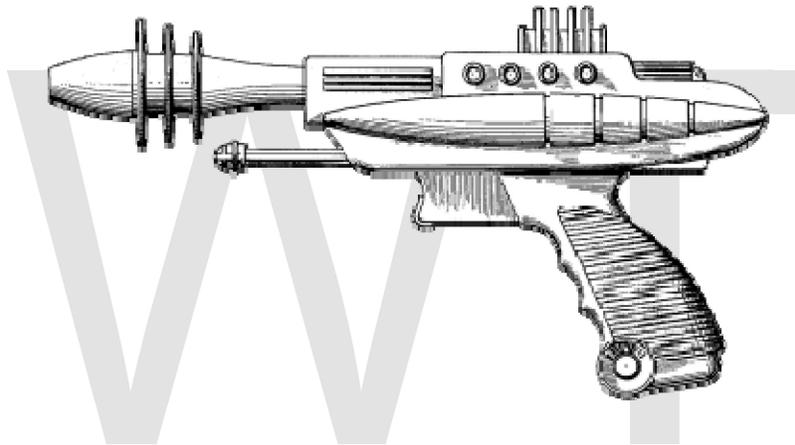
Here are some further clarifications on common areas of confusion that have already been discussed (with references) in the above sections:

1. Most nuclear weapons effects vary greatly depending upon the altitude of the detonation. This is especially true of nuclear EMP. The standard reference text on nuclear weapon effects published by the U.S. Department of Defense discusses this relationship extensively in the first two chapters, and provides mutually-exclusive definitions for phrases such as "air burst" and "high-altitude burst." As explained in above sections, nuclear detonations at all altitudes within the Earth's magnetic field will produce an electromagnetic pulse; but the magnitude of the EMP and area that is affected by the EMP are strongly affected by many factors, and is especially strongly dependent upon the altitude of the detonation. A nuclear explosion in deep space and not in a strong planetary magnetic field would be ineffective at generating EMP.
2. EMP is not a new kind of weapon effect. As stated in the "History" section above, nuclear EMP from a nuclear air burst has been known since 1945. The unique characteristics of high-altitude nuclear EMP have been known since at least 1962. Non-nuclear EMP has been known since at least 1951. Electromagnetic pulse is a prompt *secondary* effect of a nuclear explosion, and nearly all of the nuclear EMP is produced outside of the weapon. *All* nuclear weapons can produce EMP as a secondary effect, but the effect can be enhanced by special weapon design.
3. The E3 component of nuclear EMP that produces geomagnetically induced currents in very long electrical conductors is roughly proportional to the total energy yield of the weapon. The other components of nuclear EMP are less likely to be dependent on total energy yield of the weapon. The E1 component, in particular, is proportional to prompt gamma ray output; but EMP levels can be strongly affected if more than one burst of gamma rays occurs in a short time period. Large thermonuclear weapons produce large energy yields through a multi-stage process. This multi-stage process is completed within a small fraction of a second, but it nevertheless requires a finite length of time. The first fission reaction is usually of relatively small yield, and the gamma rays produced by the first stage pre-ionize atmospheric molecules in the stratosphere. This pre-ionization causes the gamma ray emission from the high-energy final stage of the thermonuclear weapon (a fraction of a second later) to be relatively ineffective at producing a large *E1* pulse.
4. It has long been known that there are many ways to protect against nuclear EMP (or to quickly begin repairs where protection is not practical); but the United States EMP Commission determined that such protections are almost completely absent in the civilian infrastructure of the United States, and that even large sectors of the United States military services were no longer protected against EMP to the level that they were during the Cold War. The public statements of the

physicists and engineers working in the EMP field tend to emphasize the importance of making electronic equipment and electrical components resistant to EMP — and of keeping adequate spare parts on hand, and in the proper location, to enable prompt repairs to be made. The United States EMP Commission did not look at the civilian infrastructures of other nations.

WWT

Raygun



A stereotypical raygun as shown in a 1955 patent application for a toy.

Rayguns are a type of fictional directed-energy weapon. They have various alternate names: **ray gun**, **death ray**, **beam gun**, **blaster**, **laser gun**, **phaser**, etc. They are a well-known feature of science fiction; for such stories they typically have the general function of guns. According to the stories, when activated, a raygun emits a ray, typically visible, usually lethal if it hits a human target, often destructive if it hits mechanical objects, with properties and other effects unspecified or varying.

Real-life analogues are electrolasers, electroshock weapons which send current along an electrically conductive laser-induced plasma channel.

History

A very early example of a raygun is the Heat-Ray featured in H. G. Wells' novel *The War of the Worlds* (1898). Science fiction during the 1920s described death rays. Early science fiction often described or depicted raygun beams making bright light and loud

noise like lightning or large electric arcs. Nikola Tesla's attempts at developing directed-energy weapons encouraged the imagination of many writers.

Soon after the invention of lasers during 1960, such devices became briefly fashionable as a directed-energy weapon for science fiction stories. For instance, characters of the *Lost in Space* TV series (1965–1968) and of the *Star Trek* pilot episode "The Cage" (1964) carried handheld laser weapons.

By the late 1960s and 1970s, as the laser's limits as a weapon became evident, rayguns were dubbed "phasers" (for *Star Trek*), "blasters" (*Star Wars*), "pulse rifles", "plasma rifles" and so forth.

Function

Ray guns as described by science fiction do not have the disadvantages that have, so far, made directed-energy weapons largely impractical as weapons in real life, requiring a suspension of disbelief by a technologically educated audience:

- Ray guns draw seemingly limitless power from often unspecified sources. In contrast to their real-world counterparts, the batteries or power packs of even handheld weapons are minute, durable, and do not appear to require frequent recharging.
- Ray guns in movies are often shown as shooting discrete pulses of energy visible from off-axis, traveling slowly enough for people to see them emerge, or even for the target to evade them, although real-life laser light is invisible from off-axis and travels at the speed of light. This effect could sometimes be attributed to the beam heating atmosphere that it was passing through.. A possible evasion tactic is dodging the firing axis of the gun, theorized in the early story of *Mobile Suit Gundam* by the character Char Aznable when he first encountered the series protagonist's machine's beam rifle and seemingly dodging it without any difficulty.

Some of the effects are what would be expected from a powerful directed-energy beam, if it could be generated in reality:

- Ray guns are often shown as transmitting heat, as with Wells' heat rays.
- Ray guns may be used to cut through hard materials like a blowtorch.

But sometimes not:

- In movies, rays are often depicted as having effect instantaneously, with a touch of the beam sufficing for the intended purpose. Raygun victims are generally killed instantaneously, often – as in the *Star Wars* films – without showing visible wounds or even holes in their clothing.
- Some rayguns cause their targets to disappear ("de-materialize", disintegrate, vaporize or evaporate) entirely, personal equipment and all.

- Occasionally a raygun is shown as transmitting cold, as with the "freeze rays" in the TV series *Batman* (1966–1968) and *Underdog* (1964–1970).
- Visible barrel recoil. This would only happen if the momentum of the beam were comparable to that of a bullet shot from a gun.
- A wide range of non-lethal functions as determined by the requirements of the story: for instance, they may stun, paralyze or knock down a target, much like modern electroshock weapons. Many of the more implausible functions are almost farcical and involve transmutation of matter such as rayguns that age or de-age people (various cartoons), or shrink rays (*Fantastic Voyage*, *Honey, I Shrunk the Kids*)

Ultimately, rayguns have whatever properties are required for their dramatic purpose. They bear little resemblance to real-world directed-energy weapons, even if they are given the names of existing technologies such as lasers, masers, or particle beams. This can be compared with real-type firearms as commonly depicted by action movies, as tending infallibly to hit whatever they are aimed at (when wielded by the heroes) and seldom depleting their ammunition.

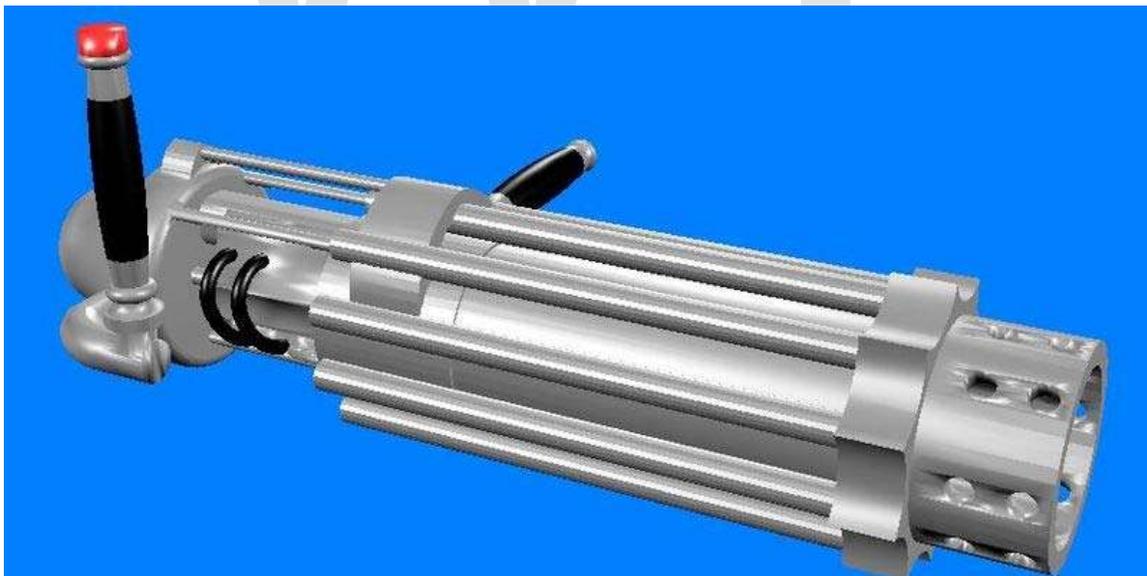
"FX-Ray laser" in American science fiction and animation is a humorous name for a raygun that shoots a visible beam: "FX" is a show business term for special effects.

Rayguns by their various names have various sizes and forms: pistol-like; two-handed (often called a rifle); mounted on a vehicle; artillery-sized mounted on a spaceship or space base or asteroid or planet. The pistol form is seen most often.

Rayguns have a great variety of shapes and sizes, according to the imagination of the story writers or movie prop makers. Most pistol rayguns have a conventional grip and trigger, but some (e.g. *Star Trek: The Next Generation* phasers) do not. The shapes of some rayguns are influenced by an opinion that they look most effective and weapon-like if they look somewhat like real guns; others, such as this, are not:



V-Gun from the Macross scenario: industrial look.



"Plasma blaster": nuclear laboratory equipment look

(The V-Gun is treated as a Gatling gunpod in Macross, but as a laser when copied as Jetfire's gun in Transformers.)

Sometimes the end of the barrel expands into a shield, as if to protect the user from back-flash from the emitted beam.

Types of raygun

The following is a partial list of notable rayguns or types of rayguns mentioned in various science fiction scenarios:

- Blasters are the standard raygun of the *Star Wars* universe.
- Disruptors or disintegrator rays, weapons disruptive of the molecular structure of matter, are used in *Star Trek* and in *Star Wars*, among other works.
- Phasers are the standard raygun of the *Star Trek* universe.
- Plasma rifles, shooting bolts of very hot ionized gas (*plasma*), are described by many works of fiction. One well-known example is the BFG 9000 in the *Doom* video games.
- Pulse rifle is the name for a wide range of fictional weapons in various works.

The ray is usually stated to be one of the following:

- Laser
- A real type of particle beam, e.g. protons and/or neutrons from the proton packs in *Ghostbusters*
- A fictional type of particle beam, such as:
 - "Minovsky particles" in the *Universal Century Gundam* series scenario, where Minovsky Physics always operate; in the *Mobile Suit Gundam 00* series, they use "GN particles" (a byproduct of a fictional topological defect baryon decay); and other timelines use other unknown particles.
 - Nadions, in the well-known *Star Trek* phaser
 - "Greek letter" rays other than the well known real-world alpha ray, beta ray, gamma ray. This includes delta rays and epsilon rays, which however have been given real-world meanings.
- Defined by a word not known in real-world science, e.g. "disruptor".
- Concussion beam: A generic term often applied to energy beams when the nature of the weapon is unknown. They are often non-lethal and only disable an opponent temporarily by knocking them out. They are often seen in television cartoons where realistic conventional weaponry is usually disallowed due to restrictions of violence.
- Undefined

Rayguns are often one-handed, sometimes two-handed, and often artillery-sized fastened to a spaceship.

Rayguns powered by a backpack powerpack are described from time to time in science fiction.

List of rayguns

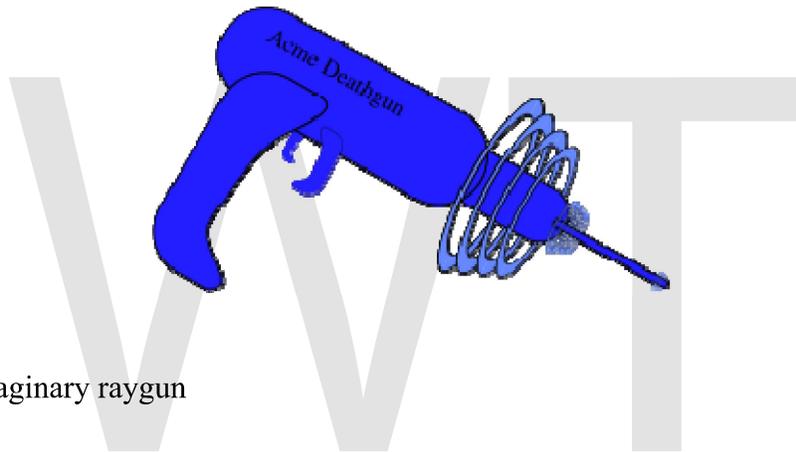
- *Alien* film series: "PIG" plasma cannon: powered by a backpack powerpack. Uses an electrolaser to create a magnetic containment bottle.
 - "Particle Beam Phalanx": cannon-sized.
- *Babylon 5*: "PPG" aka "Phased Plasma Gun"
- *BattleTech*: BattleMechs carry a wide variety of lasers, ether beamed or pulsed.
- *Blake's 7*: paragon: Federation standard issue. Image here. More Federation kit images here.
 - a pistol: Federation issue, image here.
- *Blood and Blood II*: Tesla Cannon: shoots electrical discharges
- *Captain Proton*: blaster: a lethal white electric ray
- *Command & Conquer: Red Alert series*
 - Tesla coil technology of the Soviets is in
 - Shock Troopers: elite infantry units equipped with portable Tesla coils
 - Tesla coils: large electric discharge-firing stationary coils
 - Tesla tanks
 - Tesla troopers
 - Prism technology of the Allies is in
 - Prism tanks: fire powerful light beams
 - Prism towers
 - Mirage tank: contains technology very similar to Prism technology and can camouflage
- *Command & Conquer: Renegade*: "Black Widow" (Volt auto-rifle): an electric beam
 - Firefly: a laser rifle
 - Tarantula: a laser chaingun
 - Merlin: a personal ion cannon: an instantly visible bolt of ions
- *Command & Conquer: Tiberium Wars* (novel): T7: a Tiberium-fueled laser pulse
 - EW1: a laser beam
 - Scrin cannon: a beam of Tiberium particles
- Commander Keen: wielded a red raygun in the first game
- *Crash Bandicoot*: raygun: plasma of charged particles
- *Call of Duty: World at War*: raygun: Is in Nazi Zombie mode and can be obtained in the campaign mission 'Little Resistance' through an easter egg. (note: Suggests Japanese Origin, as they did experiment with microwave technology)
- *Call of Duty: Black Ops*: raygun: Used in Zombie mode
- *Darwin's World*: role-playing game: laser rifle: Nd:YAG laser
- David Weber's novel *Apocalypse Troll*: blaster: pulse of plasma
- *The Day The Earth Stood Still*: The alien visitor Klaatu's robotic bodyguard Gort had a conventional laser beam which was shot from his 'eyes'. Not meaning any harm, Gort only used the laser defensively. It could vaporize weapons as large as a tank, or even a rifle in a soldier's hands, though the soldier would not be injured.
- *District 9*: The film's protagonist Wikus utilizes an extremely powerful directed energy weapon (manufactured by the film's resident aliens, pejoratively called prawns) that thoroughly destroys a human body on contact. Other alien weapons are used that seem to be very advanced and powerful ballistic weapons, and are

- keyed to the alien DNA, preventing them from being used by humans. None of the prawn's weapons are ever named or their workings explained.
- Doctor Grordbort's Infallible Aether Oscillators: Rayguns utilizing "infra-wave undulation" and "Phlogiston over-charging" amongst other pseudo-scientific concepts.
 - *Descent* series: laser pistols, fusion cannon, omega cannon
 - *Doctor Who*: Daleks' guns: "ruby rays", Time Lord's "Stasers", Silurians "ray guns"
 - *Doom*: Plasma rifle
 - BFG 9000: undefined (named "plasma" in *Doom 3*), unreal physics
 - *Dune*: Continuous-wave laser projectors called lasguns exist but are rendered obsolete by the use of personal Holtzman shields. The interaction of a lasgun blast and this force field results in a nuclear explosion which typically kills both the gunner and the target, to say nothing of collateral damage. Subsequently, lasguns are mostly mounted on aircraft.
 - *Edison's Conquest of Mars* (1898 sequel to ditto): disintegrator ray
 - *Fallout*: "Solar Scorcher" (runs on solar power), "Alien Blaster", various laser, plasma and pulse weapons (rifles, handguns, gatling guns, grenades)
 - *Farscape*: various weapons
 - *F.E.A.R.*: "Armacham Type-7 Particle Weapon": plasma
 - *Forbidden Planet*: hand blasters & larger blasters
 - *The Foundation Series*
 - Original trilogy: blaster: high-powered nuclear particles, shattering the target. Foundation models were seen to cause extensive damage to the surroundings, like shattering the wall behind the target.
 - Prequels: blaster: weaker. Certain models have been known to kill without producing visible damage.
 - Sequels: microwave gun
 - *FreeSpace 2*: photon beam cannons
 - *Ghostbusters*: proton pack: particle beam
 - *Filmation's Ghostbusters*: The Dematerializer: disintegrator beam (though it only works on ghosts)
 - *Gridlinked*: pulse-gun: various types of fire mode
 - *Gundam*
 - *Universal Century* series, mega beam cannons: "Minovsky particles" (and the degenerated Mega particles). (Minovsky Physics operate throughout series.)
 - *Mobile Suit Gundam 00*, "GN particles", byproduct of a fictional topological bayon decay.
 - *Mobile Fighter G Gundam*, some of the martial artist can magnify their Qi by their mobile fighter and make long range attacks similar to rayguns.
 - Undefined for other series.
 - *Half-Life*: The Gluon gun (aka the Egon), a disintegration ray, and the Tau Cannon (aka the Gauss gun)
 - *Halo* (series): various plasma weapons
 - *Hammer's Slammers*: "Powergun": a plasma pulse

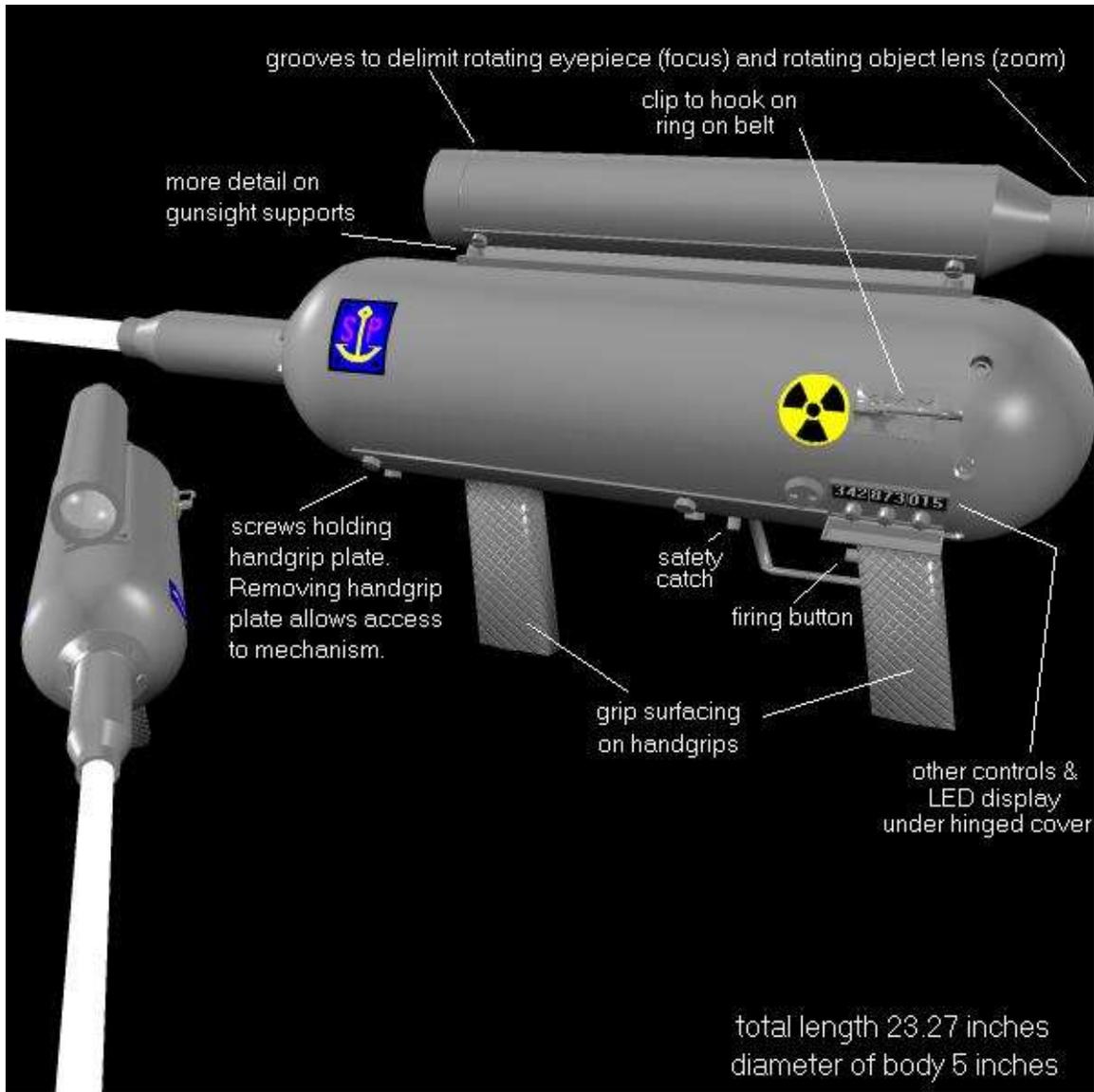
- *The Hyperboloid of Engineer Garin* (1927 novel): "hyperboloid"
- *The Hyperion Cantos*: "Death Wand": a laser-like beam weapon
- *Independence Day*: city-destroyer ray
- James Bond: *Moonraker*: "Moonraker laser": laser beam. Images: . It also appears in some videogames.
- *James Bond 007: Nightfire*: Phoenix International Experimental Laser Rifle
- *Kingdom Hearts II*: Gun Arrow: bullet-like laser beams; freezes in midair before homing in on the target
- *Kingdom of Loathing* MMORPG: Toy Ray Gun: laser beam
- *The Librarian: Quest for The Spear* (2004): Tesla's "Legendary Death Ray"
- Lucky Starr series: blasters: small slugs which on impact turn a fraction of their mass into energy
- *Mars Attacks*: Both the cards and movie feature alien weapons used by the Martians capable of disintegrating human/animal flesh, and on some occasions, terrestrial weapons and devices.
- *Might and Magic VII: For Blood and Honor*: typical blasters, similar to disintegrator guns, near the end of the game, created by the Ancients
- *Perry Rhodan* (cover of first issue (1961)) shows a rifle-shaped raygun, and a pistol in its holster.
- *Phantom Crash* (video game): scoobees or mechs carry ether shoulder or arm-mounted lasers
- *Predator (film series)*: Plasma caster
- *Quake*: BFG10K: plasma
- *Resident Evil 3: Nemesis*: "Paracelsus' Sword": a massively offensive energy beam
- *Resistance: Fall of Man*: Auger: similar to Half-Life 2's "OSIPIR"
- *Return to Castle Wolfenstein*: "Tesla Gun": a multi-targeting electric shock gun
- *Robotech*: Reflex Cannon (artillery-sized)
- *Sky Captain and the World of Tomorrow*: An unnamed raygun firing glowing rings is used by Dex.
- *Stargate*: Staff Weapon: a yellow plasma-bolt
 - intar: a red ball of energy
 - Kull disruptor: a blue blast
 - zat: a blue electrical discharge
- *Stubbs the Zombie in Rebel Without a Pulse*: raygun: a red/blue bullet of energy
 - laser shotgun: a steady blue beam of energy
 - laser RPG: a swirling mass of red and white energy
- *Super Smash Bros. series*: "Ray Gun": plasma
- *Star Trek*: Weapons of Star Trek
- *Star Wars*: blaster: blaster (Star Wars), which describes it in detail, but with unreal physics.
 - lightsaber
- *Teenage Mutant Ninja Turtles* (1987 cartoon): traditional laser guns, carried by Bebop and Rocksteady
- *Terminator (franchise)*: *Beam-weapons*

- *Total Annihilation*: may be a traditional laser, or may use coherent meson or pseudo-boson beams instead
 - Plasma Cannon: Bumble
- *Transformers (film)*: Plasma cannon, Bumblebee's secondary weapon
- *UFO: Enemy Unknown*: laser pistols, laser rifles, heavy laser
- *Unreal Tournament 2004*: "Lightning Gun": an electrolaser
- *V*: shock rifle and pistol: unknown
- *Warhammer 40,000*: numerous Imperial laser weapons (Lasgun, Laspistol, Lascannon, Volcano Cannon, Turbo-laser destructor, Ship-based Lances)
- *War of the Worlds* (1898): "Heat-Ray"
- (*various*): plasma rifle

Gallery



A typical imaginary raygun



Imaginary raygun, 2 views, with parts labelled



Small artillery sized version of same, being used.

Real-world development

- CBS in their show *60 minutes* showed a real weapon described as a raygun. This video of it shows that it is most likely the Active Denial System.
- Recent real developments of laser guns have produced artillery-sized weapons which might be described as rayguns, but usually are not.

Distinguish from

- The "RayTek laser heat gun" (at [search for heat gun](#)) is a non-contact infrared thermometer, not a gun.

Other Electronic Weapons

Electrolaser

An **electrolaser** is a type of electroshock weapon which is also a directed-energy weapon. It uses lasers to form an electrically conductive *laser-induced plasma channel* (LIPC). A fraction of a second later, a powerful electric current is sent down this plasma channel and delivered to the target, thus functioning overall as a large-scale, high energy, long-distance version of the Taser electroshock gun.

Alternating current is sent through a series of step-up transformers, increasing the voltage and decreasing the current. The final voltage may be between 10^8 and 10^9 volts. This current is fed into the plasma channel created by the laser beam.

Laser-induced plasma channel

A *laser-Induced plasma channel* (LIPC) is formed by the following process:

- A laser (possibly a laser diode) emits a laser beam into the air.
- The laser beam causes ionization of atmospheric gases to form a plasma.
- The plasma forms an electrically conductive plasma channel.

Because a laser-induced plasma channel relies on ionization, there must be air or some other gas between the electrolaser weapon and the target.

Uses

Methods of use:

- To kill or incapacitate a human target through electric shock.
- To seriously damage, disable, or destroy any electric or electronic devices in the target.

- As electrolasers and natural lightning both use plasma channels to conduct electric current, an electrolaser can set up a light-induced plasma channel for uses such as:
 - To study lightning
 - During a thunderstorm, to make lightning discharge at a safe time and place, as with a lightning conductor.
 - As a weapon, to make a thunderhead deliver a precise lightning strike onto a target from an aircraft; in this case, the aircraft and laser can be compared to a transistor, in that the relatively minor amount of initial input from the laser (base) allows a large amount of energy to flow between the cloud (collector) and the ground (emitter).

Because of the plasma channel, an electrolaser may cause an accident if there is a thunderstorm (or other electricity sources such as overhead powerlines) about.

The only defenses against electron particle beam weapons are magnetic fields, electrical insulators, capacitors, electrostatic fields, and Faraday cages.

An electrolaser is not presently practical for wireless energy transfer due to danger and low efficiency.

Examples of electrolasers

Applied Energetics / Ionatron

Publicly traded company Applied Energetics (formerly Ionatron) develops directed-energy weapons for the United States Military. The company has produced a device called the Joint IED Neutralizer (JIN) which was deemed unfit for field use in 2006 but may presently be undergoing field testing in Iraq. The JIN is intended for safely detonating improvised explosive devices (IEDs). Future designs include weapons mounted on land, air and sea vehicles and as a hand-held infantry version.

Applied Energetics said that the weapons will be able to be used as a non-lethal alternative to current weaponry, but will be able to deliver a high enough voltage jolt to kill.

Applied Energetics / Ionatron say that they are working on an electrolaser system, called LGE (Laser Guided Energy). They are also studying a laser-induced plasma channel (LIPC) as a way to stop people from going through a corridor or passageway.

Phoenix

There was an unconfirmed report that in 1985 the U.S. Navy tested an electrolaser. Its targets were missiles and aircraft. This device was known as the Phoenix project within the Strategic Defense Initiative research program. It was first proved by experiment at

long range in 1985, but this report may have referred to an early test of MIRACL, which is or was a high-powered chemical laser.

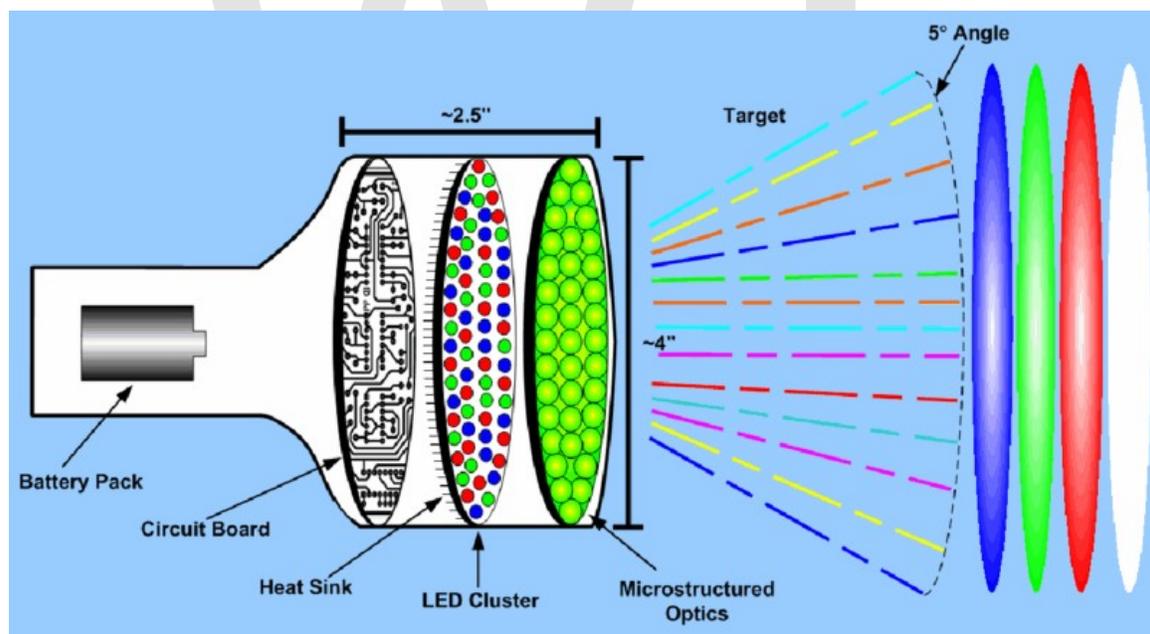
HSV Technologies

HSV Technologies, formerly of San Diego, California, USA, are designing a non-lethal device which was profiled in the 2002 *TIME* magazine article "Beyond the Rubber Bullet". It is an electrolaser using ultraviolet laser beams of 193 nm, and promises to immobilize living targets at a distance without contact. There is plan for an engine-disabling variation for use against the electronic ignitions of cars using a 248 nm laser.

Similar devices

There have been experiments in using a laser beam as path to discharge natural electric charges in the air, causing "laser-triggered lightning".

LED Incapacitator



Cross-sectional diagram of the "Incapacitator", from a DHS newsletter

The **LED (Light Emitting Diode) Incapacitator** is a weapon designed like a flashlight. It emits an extremely bright, rapid, and well-focused series of 'differently-colored random pulses.' Before the human eyes can focus in on one frequency, another frequency comes on, causing intracranial pressure, which results in cluster headaches, nausea, vomiting, disorientation, irritability, and visual impairment to the target (opponent).

The non-lethal weapon is intended as a means of protection by law enforcement officials such as the border patrol and police. The light emitted is capable of rendering opponents temporarily blind, so they can be easily subdued.

Description

According to the United States Department of Homeland Security, the weapon works:

"By simultaneously overwhelming the subject both physiologically (temporarily blinding him) and psychophysically (disorienting him). A built-in range finder measures the distance to the nearest pair of eyeballs. Then, a "governor" sets the output and pulse train (a series of pulses and rests) to a level, frequency, and duration that are effective, but safe. The colors and pulses continuously change, leaving no time for the brain or eyes to adapt. After a few minutes, the effects wear off."

The manufacturer, Intelligent Optical Systems (IOS), was awarded an \$800,000.00 contract by the United States Department of Homeland Security's Small Business Innovation Research Office. As of August, 2007, the first phase of the contract, which called for the development of a prototype, has been completed. Later phases involve the testing of the prototype by the Institute of Nonlethal Defense at Pennsylvania State University, and the development of a production version, planned to be more compact and easier to carry.

Bob Lieberman, president of IOS, said he envisions the device being used in "confrontations at border crossings with suspected illegal aliens or drug runners" among other possibilities. Projected users include "air marshals, border patrol agents, other officers with the Transportation Security Administration and customs officers" according to Gerald Kirwin of IOS. "In that few seconds, the officer has a tactical advantage and will actually close in to subdue or control the potential adversary," Lieberman said. The device can be used from ranges of up to 30 feet, while other non-lethal devices require an officer to approach the target much more closely, according to Lieberman.

Glenn Shwaery, a researcher into nonlethal technology at the University of New Hampshire, says "If you disorient or distract somebody and cause them to look away, then they can't focus on their task, which could be aiming a weapon at someone, or looking at a screen with sensitive information, or dialing a phone." Shwaery says that an LED-based device could be safer than a laser-based device intended to achieve the same effects "Getting an eye-safe wavelength with a laser has been very difficult." Shwaery says that the presence of a range-finder and circuitry to modify the intensity of the light depending on the range in the LED device increases its safety. "The ideal goal for nonlethal technologies is that they be scalable." It was intended to be released to police, boarder patrol agents and National Guardsmen by 2010.

Deficiencies

Some test subjects have been completely unaffected by the light, and although the manufacture makes wide and un-based claims about the product's effectiveness, the CEO of Intelligent Optics, the producer of the device, has actually commented "I don't think we've had anyone actually be sick"

Criticism

Some critics have questioned the desirability of developing and deploying such a device for border security use. Deborah Notkin, president of the American Immigration Lawyers Association said: "It gives me pause, particularly in regards to Mexico. Mexico is a very important economic partner of ours. I would imagine that Mexico wouldn't be particularly happy with us using a device that would be more appropriate for criminals, not just for people trying to get across the border who are looking for better opportunities."

Peter Herby, head of the legal division of the "mines-arms unit" at the International Committee of the Red Cross, suggests that such a device may raise many of the same issues as have arisen with laser-based blinding weapons, known as "dazzlers" because of the intense light with which they temporarily or permanently blind people. He also raises the issue of a possible black market in such weapons. "Once they're in the hands of bad guys are the police going to have to wear protective gear to prevent them[selves] from being dazzled?" Herby states that he is not familiar with this specific device.

However Lieberman of IOS says: "We're taking great care to make sure the intensities we're using fall within eye-safe limit. We're doing medically supervised tests."