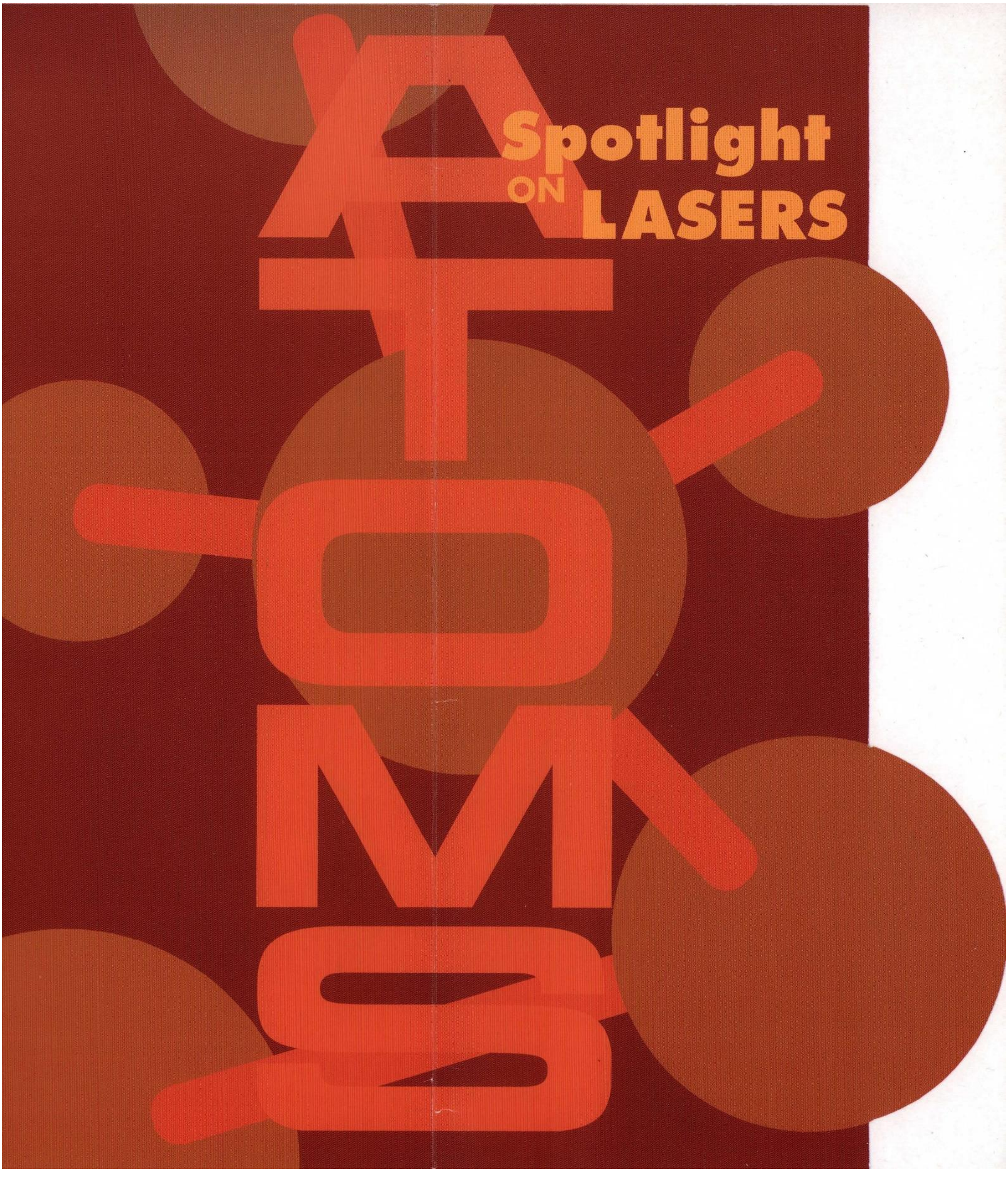


ATOMS

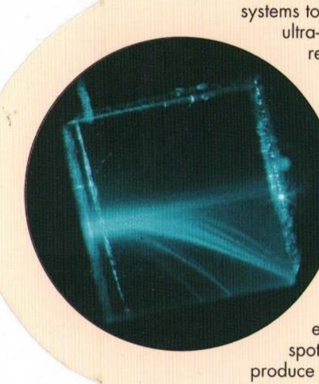
Spotlight ON LASERS

Lasers at Work

Laser light is very different from the light produced by, say, a torch. It spreads out less, it contains light of only one colour, or wavelength, and it can be produced in intense pulses.

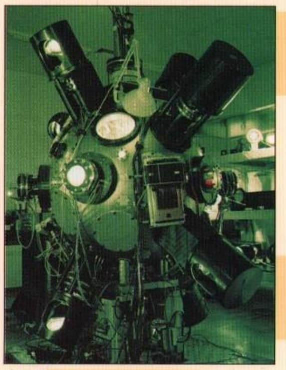
The unique properties of laser beams mean that they can be applied to a wide variety of problems in physics, chemistry, and biology.

The facilities at RAL have been developed so that UK scientists have access to 'state-of-the-art' laser systems to carry out their research. RAL lasers, with ultra-high power, brightness, colour tuneability, repetition rate, and ultra-short pulse length, are used to solve a great variety of problems. Studies range from simulating conditions at the centre of the Sun to watching the work of vitamins undertaking cell repair.



Plasmas

Just as a magnifying glass can be used to focus sunlight to a spot which can heat matter to a high temperature, a laser beam can be focused to an extremely small spot and so produce matter at extreme temperatures. The irradiance of sunlight at the focus of a magnifying glass will be about 10^2 watts per cm^2 whereas the beams from the Vulcan and Titania lasers can be focused to 10^{19} watts per cm^2! The temperature produced is so high that atoms are broken down into their component parts – electrons and ions – creating the plasma state of matter.

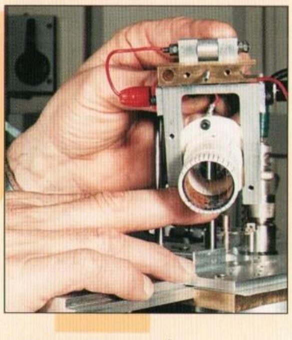


The fusion of hydrogen into helium, a reaction which takes place in the plasma at the centre of the Sun, produces the energy on which we all depend but it requires enormous pressures and very high temperatures to start the fusion process. With Vulcan, we can simulate, for less than a nanosecond, conditions at the centre of the Sun. Work at RAL is directed towards understanding Inertially Confined Fusion (ICF), where fusion occurs briefly before the plasma has time to expand and cool. Experiments on the plasmas created with Vulcan may ultimately lead to power stations fuelled by fusion.

X-rays from Laser Plasmas

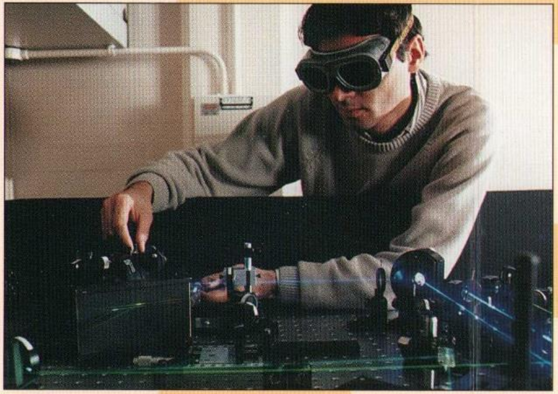
High temperature laser plasma is a source of copious X-rays which can be used to produce photographic images of the structure of living biological specimens with a single laser shot. The short exposure time avoids the problem of radiation damage to the specimen. Such incoherent X-rays can also be used to produce electronic microcircuits which, due to the much shorter wavelength of X-rays compared to visible radiation, will be much smaller than the present generation which are produced using ultraviolet light.

Vulcan has been at the forefront of research into coherent sources of X-rays which are in X-ray lasers. The ultimate challenge of this research is to build an X-ray laser with a wavelength of between 2.2 and 4.4 nanometres. In this region water is transparent but carbon is not, so it would be possible to produce an X-ray hologram of the molecular structure of living tissue.



DNA Repair

There are many events in the lifetime of a cell which will damage its DNA and the cell must have a quick and perfect method of repair if it is to survive. Scientists from Birmingham University have been using RAL lasers to examine the repair process. Each of DNA's two strands carries the same genetic information and the cell compares one with the other to rectify damage. The scientists damage cellular DNA with a flash of laser-produced X-rays, then pulse another laser to activate a specially introduced molecule which inhibits the repair process. With this experiment , they discovered that within a few seconds of the damage done by X-rays a 'panic phase' repair is started.



Biochemists, biologists, physicists and computer experts are all involved in this work. If we can find out about DNA repair processes at this level it might one day be possible to design drugs which stop repair in cancer cells so that they die while healthy cells live.

Fast Chemical Reactions

Chemists use lasers to study chemical systems. Pulsed lasers such as those at RAL's Lasers for Science Facility are used to investigate the mechanisms of chemical reactions – which intermediate chemical compounds are formed between the beginning and end of a reaction, for example. A laser pulse starts (pumps) a reaction and the resulting compound is observed (probed) by some other technique. The probe is often a second pulsed laser – the single wavelength nature of the laser is used to good effect in spectroscopy – identifying chemical compounds by observing the light they absorb or emit.

Scientific Notation

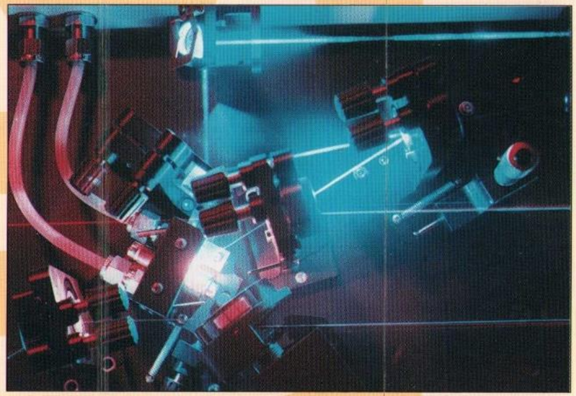
Words like a million and a millionth cannot begin to describe the scale of the huge power of lasers at RAL and the tiny fractions of a second used to measure the duration of laser pulses. Scientific notation describes just how big or small a quantity is, as shown in the table (right).

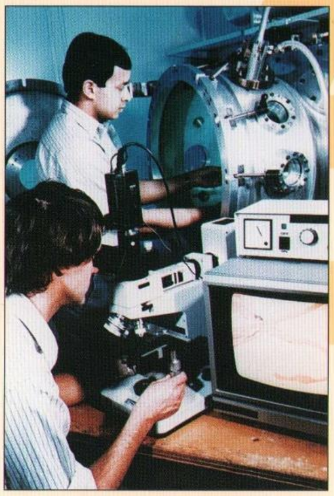
Thus, a million (1 000 000) is written as 10^6, and the prefix used is 'mega' as in megawatts of power. A millionth, 10^{-6}, is described as 'micro' such as a microsecond – a millionth of a second.

Notation	Name	Symbol
10^{15}	peta	P
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
$10^0(=1)$		
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

The Role of Vitamins

Lasers are used to study the way that vitamins E and C protect us from harmful molecules that can cause cancer and heart disease. The work has shown that after vitamin E has chemically neutralised a harmful molecule known as a 'free radical', the vitamin E can be regenerated by vitamin C and go on to repeat the life saving process.





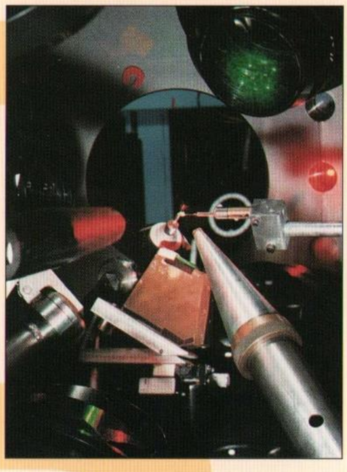
Using lasers which can give out light in pulses shorter than a picosecond, it is even possible to observe the changes which go on inside a single molecule immediately after the absorption of a photon.

VULCAN

VULCAN is a multi-beam, multi-terawatt Nd: glass laser facility capable of both long pulse (1ns) and short pulse (sub-ps) operation. The system is uniquely versatile delivering 2500 Joules in a 1ns pulse synchronised to a 1ps pulse of 35 terawatt power.

The short pulse facility uses chirped pulse amplification (CPA), a technique which overcomes the problems of propagating ultra-short pulses through non-linear media by streaching them prior to amplification. This delivers focused intensities to target of 10^{19} Wcm^{-2}. Developments are underway to enhance the output capabilities to >200 TW in Phase I of a two phase PetaWatt enhancement programme.

Vulcan can be configured in various geometries including line focus and cluster, and can be switched rapidly between four target interactions areas. This enables VULCAN to support a very broad scientific programme, including: x-ray lasers; gas and solid target interactions; and ICF related physics.

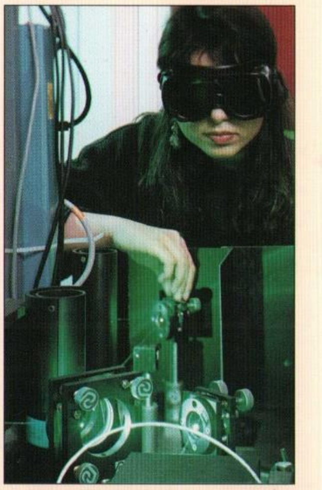


TITANIA

Titania, opened in April 1996, is the world's brightest source of ultraviolet laser light. The extreme brightness of the beam allows its users to study new and exciting areas of physics involving the interaction of ultra-high electric fields with matter.

Titania is a krypton fluoride gas laser which employs the techniques of chirped pulse amplification (CPA) and Raman beam combining to achieve its very high performance. These techniques have been developed over an extended period at RAL, which has become a world leader in these fields.

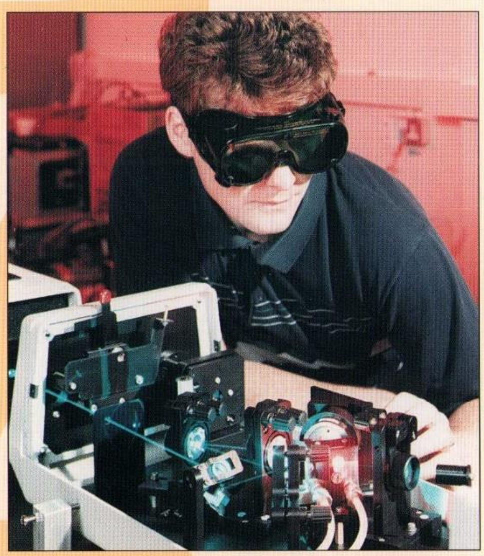
At a rate of one shot every few minutes, Titania can now deliver energy to target in pulses of a few hundred femtoseconds duration, producing an intensity of greater than 10^{19} W cm^{-2}. Higher intensities are becoming available as improved system components are brought on line. The implementation of the Raman system will lead to comparable intensities associated with substantially higher energies and longer pulses.



TUNEABLE LASERS

Lasers for Science Facility (LSF)

The LSF offers researchers a diverse range of laser techniques, many unique with wavelengths from the vacuum ultraviolet to the infrared and pulse durations from femtoseconds to nanoseconds. The LSF also has the World's brightest laser produced plasma X–ray source, 1 Watt average power at 1 nm. Staff are keen to promote the use of lasers in all fields of research and provide expert advice to users. Research spans chemistry, physics and biology with expertise in fast chemical reactions, DNA repair, silicon chip manufacture and laser microscopy.



The facility also runs a Laser Loan Pool which makes lasers available to researchers at their own laboratories. Scientific investigations include the chemistry of interstellar clouds and high resolution spectroscopy.

RAL Central Laser Facility

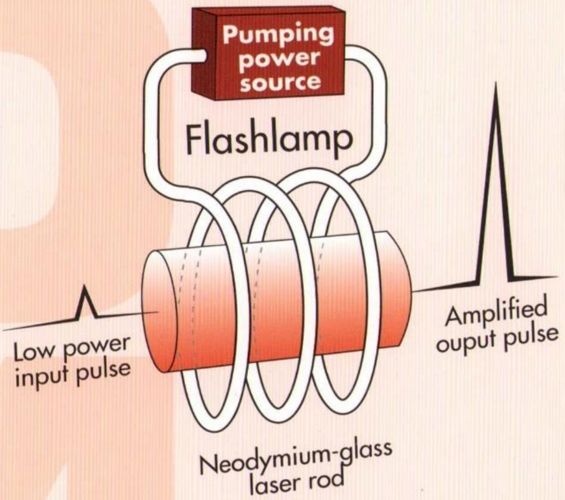
RAL is a large, multi-disciplinary laboratory involved in a broad range of scientific and technological activities. Our main function is to support academic research by developing and operating large facilities in a wide variety of scientific fields, including space science, lasers, atomic structure, particle physics, computing and information technology.
The Central Laser Facility at RAL is one of the world's leading centres for high power laser research. Two large lasers, Vulcan and Titania, are in operation and their continuing development maintains the Facility at the forefront of the laser field. In addition, the Lasers for Science Facility maintains a wide range of smaller lasers for use at RAL or on loan to universities around the country.

LASER: Light Amplification by Stimulated Emission of Radiation

How a Laser Works

Lasers are light amplifiers. If we shine a light beam in at one end a more intense beam emerges at the other. There are many hundreds of different kinds of laser which amplify visible light, infrared light or ultraviolet light.

In order to amplify light, energy needs to be pumped into the laser. The process is rather like pumping up a balloon. The power we use in pumping up the balloon is small, but the balloon stores the total energy (power x time) as air under pressure. When the balloon is burst, this energy is released in a short time, giving a high output power. The same principle applies to pulsed lasers: in a neodymium-glass laser, for example, the pumping time is typically one millisecond. The energy is then released in a nanosecond giving a million times increase in power.



As energy is pumped in, the atoms inside the laser material become excited (raised to a higher energy level). As they fall back to their original energy level, they emit photons (packets of light). If one of these photons hits an excited atom, another photon is emitted which is exactly in phase with the first. This is stimulated emission of radiation. These two identical photons can each produce two more and so on, leading to an every increasing army of identical photons. This amplification of light by stimulated emission of radiation leads to a beam of light where all the photons are in phase and travelling in the same direction. Such a beam can be focused to extremely high irradiance.

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