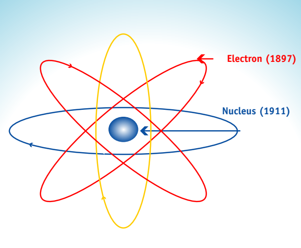
LIGHT STRONGER THAN MATTER

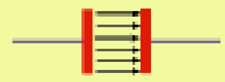
The 'strength' of matter



Electrons are bound in atoms by electrostatic attraction. The simple Bohr model predicts that the strength of the electric field binding the electron is ~ 2 x 10^{11} Vm^{-1} . This defines the 'strength' of atoms.

"Are not gross bodies and light convertible into one another; and may not bodies receive much of their activity from the particles of light which enter into their composition? The changing of bodies into light, and light into bodies, is very conformable to the course of Nature, which seems delighted with transmutations." Newton.

Since the mid 1980's there has been a revolution in the power that can be delivered by pulsed lasers. Short-pulse lasers with peak powers of order a terawatt (10^{12} W) can be found in many University physics departments. A terawatt is roughly equivalent to the power produced by the whole of the UK national grid at any point in time! When focussed with mirrors to small spots, the irradiance can exceed 10^{24} Wm^{-2} !



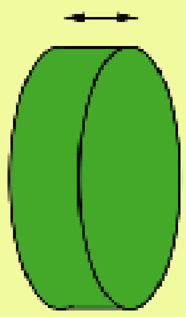
The energy stored in a capacitor of area A and plate separation d with an electric field E between the plates is:

$$U = \frac{1}{2}C(Ed)^2 = \frac{1}{2}\left(\frac{\epsilon_0 A}{d}\right)(Ed)^2$$

Therefore the energy per unit volume in the field is:

$$\frac{U}{Ad} = \frac{\epsilon_0 E^2}{2}$$

A short pulse laser with pulselength τ produces a 'pancake' of light of area A and thickness $c\tau$. Using our formula for the energy density in the capacitor, we can find how the electric field in the light is related to the irradiance I (power per unit area):

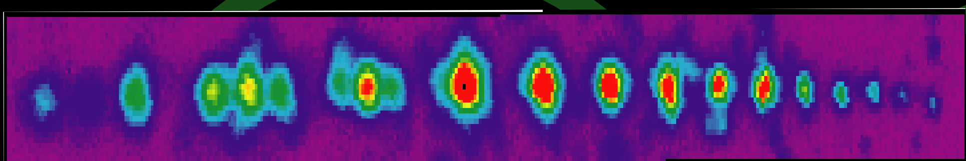


$$\frac{U}{c\tau A} = \frac{I}{c} \approx \epsilon_0 E^2$$

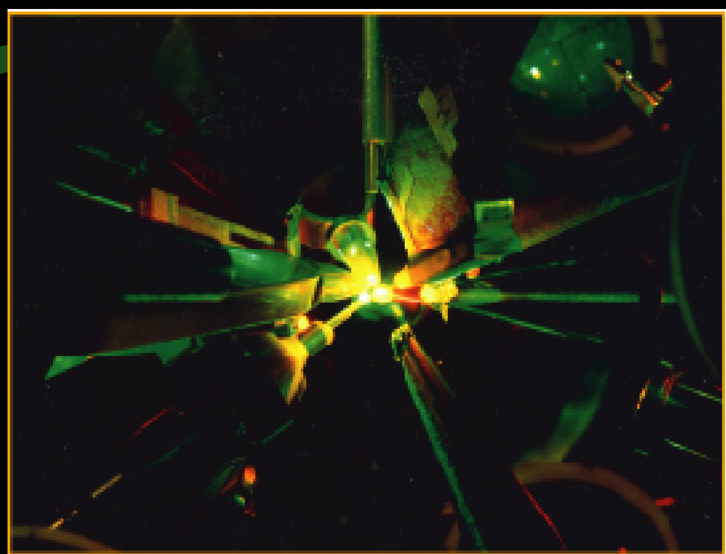
$$E \approx \sqrt{\frac{I}{c\epsilon_0}}$$

Light is an oscillating electromagnetic wave. How do we calculate the value of the electric field in the light? Well, a simple way is to notice how the electric field is related to the energy density in a capacitor, and then to apply the same formula to light.

Having found the formula for the electric field for light of of a given irradiance, we can show that the electric field of the light equals that in the atom when the irradiance of the laser is approximately 10^{20} Wm^{-2} (ten thousand times less than irradiances that can be produced). When such light is shone on atoms, the electrons are ripped away from the nucleus. The motion they experience while being pulled away from the nucleus can cause them to produce high harmonics of the light, just as a stringed instrument produces harmonics.



The spectrum of harmonics produced when a high power laser passes through a gas of Neon atoms.



Photograph courtesy of CLF, CLRC

Physicists at Oxford work on the VULCAN laser at the Rutherford Laboratory (right), high power lasers in the United States, as well as operating their own terawatt laser. They investigate strong field effects in atoms, and use the world's most powerful lasers to study matter at extremes of temperature, density and pressure.

Photograph courtesy of CLF, CLRC

Light has momentum, but normally we cannot feel the push of light. When these lasers are focussed to small spots, the momentum change of the light upon reflection causes a pressure which is greater than that at the centre of the sun!

If you want to know more about Physics at Oxford see the web: http://www.physics.ox.ac.uk/

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Oxford Physics is grateful for support from the IoP