

# The Coherent Raman Effect on Incoherent Light (CREIL).

The **CREIL** is a radiation transfer of ordinary incoherent light. It is based on ISRS (Impulsive Stimulated Raman Scattering) ISRS has been demonstrated in laboratories by using ultra-short light pulses. When two frequencies of light are pulsed in the same low pressure chamber, the 'warmer' of the two pulses exchanges energy with the 'cooler', resulting in frequency shifts of both pulses.

ISRS and CREIL obey the same theory, but very different parameters must be used to demonstrate the CREIL effect. In both processes light pulses must be ultra-short, that is "shorter than all relevant time constants". ISRS can be demonstrated in dense matter having infrared quadrupolar resonances. Ultra short burst of light at very high intensities must be used, and the frequency shift depends on the peak intensity of the light. In contrast, CREIL requires a low pressure gas with resonance stabilities in the megahertz range. Since the low pressure of the gas limits collisional scattering transitions, CREIL effects do not depend on the intensity of the light. Consequently, while the observation of CREIL in a lab would require a very long and expansive multi-path cell, ISRS is easily observed, confirming the common theory of both effects.

The CREIL is a frequency shift of light beams refracted by a convenient medium. It increases the entropy of the **set** of beams whose temperature is deduced from Planck's law. Generally, the frequency of light is decreased (redshift), the frequencies of radio and micro waves are increased (blueshift).

## Let us recall the refraction by a transparent medium:

*Elementary theory.*

A thin sheet of matter between two wave surfaces distant of  $\epsilon$  radiates a fraction  $K\epsilon$  of the incident amplitude of light by a coherent Rayleigh scattering. With usual notation, the interference of the incident beam and the scattered beam delayed of  $\pi/2$  gives the field:

$$E = E_0[\cos(\Omega t) + K\epsilon \sin(\Omega t)] = E_0[\cos(\Omega t) \cos(K\epsilon) + \sin(K\epsilon) \sin(\Omega t)] = E_0 \cos(\Omega t - K\epsilon) \quad (1)$$

The index of refraction  $n$  is defined setting:

$$K = 2\pi n/\lambda = \Omega n/c \quad (2)$$

*Look at the origin of the Rayleigh scattering;*

Perturbed by the electromagnetic field the matter emits the delayed wave. The previous definition of the index of refraction without a reference to the amplitude  $E_0$  works at the lowest amplitude, showing that all molecules of the refracting medium radiate a field, having absorbed temporarily an infinitesimal, not quantified energy, to reach a non-stationary (or dressed) state. This energy is returned to the wave when its field decreases.

*Interaction between dressed states:*

While two dressed states of the whole medium generally radiate geometrically different waves, two molecular dressed states have the same symmetry, so that they may interact through a symmetrical interaction, that is a Raman type interaction. This leads to split the CREIL into interacting Raman coherent scatterings, remembering that the balance of energy must be zero when the matter returns to its stationary state.

**Adding a Raman space-coherent scattering to the Rayleigh coherent scattering: the CREIL.**

A light-matter interaction is space-coherent if the differences of the phases of all involved waves at each molecule is the same for all molecules (for refraction, it is  $\pi/2$ ). Try the previous computation using a Raman Stokes scattering; (1) is replaced by:

$$E = E_0[\sin(\Omega t)(1-K'\epsilon) + K'\epsilon \sin((\Omega+\omega)t)] \quad \text{with } K' > 0$$

The first infinitesimal term containing  $K'\epsilon$  is needed for the conservation of energy at  $t$  small.  $K'\epsilon$  is infinitesimal, and we must assume  $\omega t$  small to continue the computation:

$$E \cong E_0[\sin(\Omega t)(1-K'\epsilon) + K'\epsilon \sin(\Omega t)\cos(\omega t) + K'\epsilon \sin(\omega t)\cos(\Omega t)]$$

$$E \cong E_0[\sin(\Omega t) + \sin(K'\epsilon\omega t)\cos(\Omega t)] \cong E_0[\cos(K'\epsilon\omega t)\sin(\Omega t) + \sin(K'\epsilon\omega t)\cos(\Omega t)] \\ = E_0 \sin[(\Omega+K'\epsilon\omega)t] \quad (3)$$

For Stokes scattering,  $K'$  is replaced by a negative  $K''$ .  $K'+K''$  is proportional to  $\exp(-h\omega/2\pi kT)-1$ , approximately to  $\omega/T$ . Thus, the frequency shift is proportional to

$$\Delta\Omega = (K'+K'')\epsilon\omega \text{ proportional to } \epsilon\Omega\omega^2/T. \quad (4)$$

As in refraction, the  $K$ s are proportional to  $\Omega$  if the dispersions of the polarisabilities are neglected. Thus  $\Delta\Omega/\Omega$  is nearly constant. The elementary frequency shifts add along a light path without blurring the images and the spectra.

*G. L. Lamb's condition.*

It is difficult to obtain the space coherence when several frequencies are involved because the corresponding wavelengths are generally different, so that the differences of phases are generally different jumping from a molecule to an other. Tricks are required. The most powerful, used to multiply, more generally combine laser frequencies is using two indices of refraction of a crystal. An other is truncating the waves, so that the differences of frequencies do not appear. This truncation may result from geometry, Lamb set a purely temporal condition: "The length of the light pulses must be shorter than all relevant frequency shifts". We have written such a condition supposing  $\omega t$  small. It is necessary too that the collisional time be longer than the length of the pulses.

### **Experimental verification.**

Using femtosecond pulses, the experimental verification is easy in an optical fibre. A complete study is easier using the improvement of the effect resulting from the non-linearity induced by the high power of the femtosecond lasers. It is the "Impulsive Stimulated Raman Scattering" extensively studied in some laboratories.

Using the nanosecond pulses which make the ordinary light requires the use of a low pressure gas having Raman resonances at frequencies of the order of 100 MHz in well populated states. It would require an expansive experiment which does not seem useful because the extrapolation from the laser experiments seems reliable, and the experimental conditions in the solar system are well known.

### **Application to hydrogen.**

In its ground state, atomic hydrogen has the Raman type resonance at 1420 MHz which is too high. In the first excited state, the 2S and 2P states (written H\*) have convenient frequencies; in upper states, the populations and the frequencies are low: the  $\omega^2$  term in equation 4 shows that the effect becomes negligible.

If the pressure is sufficient to reduce the dissociation, very hot hydrogen (100 000 K) contains the convenient excited states.

Consider hydrogen at 10 000 K. It is atomic. Suppose that a continuous, far ultraviolet rich spectrum crosses it; hydrogen is pumped to the 2P state by a Lyman  $\alpha$  absorption so that it redshifts the light; the physical conditions split the gas into shells:

- "Shifting shells": In the "S" shells, the intensity and therefore the pumping are large enough to shift the region of the spectrum absorbed by the Lyman  $\alpha$  line out of the line, so that the absorption is fed, there is a continuous frequency shift until the UV or the gas disappear; the absorbed or emitted lines get the width of the shift, so that they are usually undetectable.

- "Normal shells": In "N" shells, the pumping is too low for a continuous shift; there is a normal absorption.

At the limit "S" to "N", a previously absorbed line stops the "S" phase, starting a "N" phase; at the limit "N" to "S" side effects such as shifts by very excited states, and population of 2S state by decay from high levels..., restart the redshifts.

### *Karlsson Periodicity.*

Suppose that the shells are generated by the light from a small source, and that a previously absorbed line starts a "S" phase. At first, consider only Lyman  $\alpha$  and  $\beta$  lines. The "S" phase is stopped when the  $\beta$  absorbed line is shifted to the  $\alpha$  frequency, all frequencies being multiplied by the ratio of frequencies  $\nu_\alpha/\nu_\beta$ . The  $\beta$  line being absorbed during this "S" phase, a succession of phases multiplies the frequencies by a power of  $(\nu_\alpha/\nu_\beta)$  that we write  $((\nu_\alpha/\nu_\beta)^{1/3})^p$ , where p is a multiple of 3. Replacing the  $\beta$  line by the  $\gamma$  line, the frequencies are multiplied by a power of  $\nu_\alpha/\nu_\gamma$  written  $((\nu_\alpha/\nu_\gamma)^{1/4})^p$ , with p a multiple of 4. It happens that

$((v_\alpha/v_\beta)^{1/3}) = (108/128)^{1/3} = 0.94494$  and  $((v_\alpha/v_\gamma)^{1/4}) = (108/135)^{1/4} = 0.94574$ , so that, with a precision of 1/1000, the frequencies appear as multiplied by a power of 0.945. Considering simultaneously both lines, the power  $p$  can get almost all integer values. Usually, the result is written using logarithms to avoid powers and observe directly the period:  $\log((v+\Delta v)/v) = p \log(1/0.945)$ .

### **Astrophysical applications.**

The use of Karlsson's periodicities is the key of the study of the very complicated spectra of the quasars: their spectrum is obtained supposing that they are micro-quasars (fast moving neutron stars of the galaxies), which find a relatively high density of hydrogen when they leave their galaxies.

Molecular hydrogen pumped in its Lyman region shows much more difficult to observe periodicities. These Tiffit-Napier periodicities correspond to shells around the galaxies.

It seems that a Karlsson redshifting spherical shell built around SN1987A produces its pearls necklace, a competition of modes in the tangential superradiance making the bright dots.

The cooling of the solar wind beyond 10 astronomical units produces metastable 2S atomic hydrogen which catalyses a transfer of energy from solar light to microwaves. Thus, the Pioneer 10 and 11 probes seem having an anomalous acceleration to the Sun because the frequencies of their radio signals are increased; the same transfer of energy explains than a part of the anisotropy of the microwave background is bound to the ecliptic.