Synchrotron Light Sources and Alternatives

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Abstract. A comparison between a Synchrotron Light Source (SLS) and other light sources is presented. Among them the so called Compact Light Sources based in the Inverse Compton Scattering (ICS) are already commercially available and are given special attention. The physical basis of each light source is considered. The present status of The Mexican SLS is presented and the need to a practical access to external SLS is stressed.

Key words: Light Sources, Synchrotron Light Sources, Compact Light Sources, High Harmonic Sources, Plasma Sources. Plasma Accelerator methods.

Introduction. Light sources are one of the main tools of research that are available in science, technology, innovation and even art. Continuous improvement and invention of procedures to harness the possibilities of electromagnetic radiation has taken place for several centuries since the invention of optical devices such as the telescope and the microscope. The most influential treatise in Opticks in the early XVIII century was Newton study of Reflection, Refraction and Inflexions of Light, that lead its author to conclude that light was made of corpuscles. It was not until the end of that century that he was shown wrong by the Young experiment that discovered the interference of light waves.

The young H. Hertz in the 1879 began to consider the Maxwell prediction of electromagnetic waves, then in a struck of genius he demonstrated that sparks produced by an induction coil could induce sparks in an independent electrical circuit located at a distance and concluded that waves produced by sparks in the first circuit were actually traveling to the second one. Curiously Hertz concluded “I do not think that the wireless waves I have discovered will have any practical application”. In a few years his misjudgement was to be corrected by Marconi and others. From a more fundamental point of view, Hertz discovery is the foundation that today ensures that electromagnetic radiation includes a vast kind of waves from the hetzian radiowaves, microwaves, infrared, visible light, ultraviolet, X-ray and to the gamma rays. In fact, that the ancient science of Opticks is part of electromagnetic phenomena. In this way his discovery opened the way for relativity and quantum physics and two one of the great and puzzling modern physics paradigms the wave-particle duality. Newton and Hertz were neither right nor wrong, Mexican politicians in a modern synthesis might have added: all to the contrary they are both right and wrong because light is a wave and a particle at the same time. To add to our astonishment that things that in the XIX century were firmly considered particles, all of them have wave properties, my electron microscopist colleagues won’t let me lie.

And yes, we might continue arguing about the nature of light and electrons, but we know for sure how to use it as one of our primary probes to understand the Renum Natura, the Nature of Things. In order to do that we have to build particle and wave detectors ever more potent and samples to be observed ever more pure and exquisite. But also light sources which take advantage of more properties of our probing beams. Thus lasers have changed the way in which we can produce coherent light mainly in the microwave and up to the ultraviolet range. A laser can also be tuned in a relatively short region of the electromagnetic spectra, we do not have lasers that go into shortest wavelengths.

HHG Sources. One relatively new light source that uses an optical laser as the driving mechanism are the so called High Harmonic Generators -HHG- Sources. Depending on the gas and the wavelength of the laser one can excite the electrons of the gas and for a high enough intensity of the gas the electron due to the coherence of the laser began to oscillate in higher harmonics, in terms of a quantum description one can understand this as the absorption of several photons, the total number of photons absorbed will give different harmonic motions to the accelerated electron that will radiate preferentially into the highest frequency that it is excited. With this model in mind one can predict that a laser of high longitudinal and temporal coherence is required and that the intensity of the Higher Harmonics will eventually decay. The best HHG sources in fact can only be tuned up to the ultraviolet region and efforts are being made to extend it to higher frequencies. Some very interesting properties are present in these sources. One extremely important one is that the wave produced inherits the coherence and time structure of the laser. Thus one gets...
pulses of femtoseconds. One of the challenges of this kind of source is that the intensity of the higher harmonics is many orders of magnitude smaller than the original laser, a second difficulty is that in order to get a different set of harmonics the gas must be changed. On the other hand this design is relatively compact and does not require astronomical budgets.

Compact Inverse Compton Effect Sources. Another compact lightsource architecture is provided by the Inverse Compton Effect (ICE). In the original Compton effect the initial electron sits in an atom with a binding energy much smaller than the photons in the initial light beam; the electron at rest gets the kick of the photon an the two go into final states, because energy is conserved the initial photon loses energy while the final electron gains it. In the ICE an electron of several MeV of energy collides with an optical photon of a few eV, again the collision is elastic, when the collision is head on the electron losses energy that is gained by the photon. When the energy of the photon is in the 30 MeV range an the photon, typically from a laser beam, is 1 eV or less one gets the bounced back photons in the soft X-ray region. This effect is used in the commercially available Compact Light Sources of the Lyncean Company, the conceptual design uses a beam of a 20-40 MeV electron synchrotron which has a straight region into which a laser cavity is fitted in. A strong focusing of both photon and electron beams are critical to get a bright final scattered photon beam, the final photon angle varies in intensity and energy with the scattering angle according to a generalization of the Compton formula.

An alternative approach is to substitute the synchrotron with a much more intense linear accelerator, in order to recover the energy of the beam after the collision with the laser beam one has to resort to an accelerator with Energy Recover architecture, this idea is being pursued in Japan and at MIT in the USA. In the mean time the Lyncean Company architecture is mainly used for imagnology experiments with a photon flux comparable to the second generation non-compact synchrotrons.

Synchrotron Light Sources. These sources are most easily understood in terms of two basic concepts: the electromagnetic radiation predicted by Maxwell equations for a pointlike charge distribution that is known as the Léonard-Wiechert potentials that leads to the Larmor formula for the total power emitted is proportional to the square of the product of its electric charge times the acceleration of the particle and the second condition that follows from the fact that Maxwell theory is covariant under the Einstein special relativity. It follows that the light emitted when the charge, let us say an electron accelerates and its velocity is close to the velocity of light all the power is deposited into a cone in the forward direction of the light and the angle of the cone vertex that sits in the electron has an angle proportional to the quotient of the mass of the particle to its kinetic energy, additionally the light is linearly polarized in the acceleration direction. For largest electric, \( E_{\text{max}} = 15 \text{ MeV/m} \), and magnetic fields, \( B_{\text{max}} \approx 10 \) Teslas, that can be obtained in the laboratory the magnetic field is much larger and the acceleration produced by the magnetic field is perpendicular to the velocity. It turns out that for a few GeV electron guided in a circle of 100 m diameter a non-negligible amount of energy is lost to radiation per turn and that the peak of the radiated energy is in the x-ray region. The spectra of the light is one of the most intense and brilliant from the infrared to the x-ray region that can be attained in the laboratory. All these properties make electron synchrotrons a work horse as light sources. At the same time the energy loss limits the use of synchrotrons as high energy electron accelerators. There are some 50 synchrotron specialized in the production synchrotron light the continuous spectra and the large circles that are needed allow multiple experiments to be performed simultaneously. And the brilliance (the number of photons per second per unit area in a small percentage of bandwidth make it very efficient installations for research in many disciplines from material sciences, physics, chemistry, biomedicine and also in industrial research and cultural heritage conservation, paleontology and antropology. In the last 20 years further development has further increased the possibilities of these sources: the insertion devices the main effect is to multiply the brilliance of the Synchrotron Light Sources and its discovery potential. A more recent refinement of the control of the electron beam makes possible to foster the brilliance up to the so called diffraction limit at the X-ray level making their capabilities closer to the ones in a Free Electron Laser. With all these flashing properties the come with a serious disadvantage: the initial inversion is high, although the price per experiment is comparable and with a superior average quality of a regular source.