(ELI-NP at Magurele - "Pulse and Impulse of ELI")

Extensive Light Investigations-ELI-apoma Laboratory

1) "**Polaritonic pulse** and coherent X- and gamma rays from Compton (Thomson) backscattering" (MA&MGan), J. Appl. Phys. **109** 013307 (2011) (1-6)

2)"Dynamics of **electron–positron pairs** in a vacuum polarized by an external radiation field" (MA), Journal of Modern Optics, **58** 611 (2011)

3)"**Classical interaction** of the electromagnetic radiation with two-level polarizable matter" (MA), Optik **123** 193 (2012)

4)"**Coherent polarization** driven by external electromagnetic fields" (MA&MGan), Physics Letters **A374** 4848 (2010)

5)''Coupling of **(ultra-) relativistic atomic nuclei** with photons'' (MA&MGan), AIP Advances **3** 112133 (2013)

6)''Propagation of **electromagnetic pulses** through the surface of dispersive bodies'' (MA), Roum J. Phys. **58** 1298 (2013)

7)''**Giant dipole oscillations** and ionization of heavy atoms by intense electromagnetic pulses'' (MA), Roum. Reps. Phys. **67** 837 (2015)

8)''**Parametric resonance**'' in molecular rotation spectra'' (MA&LC), Chem. Phys. **472** 262 (2016)

9)''**Motion of an electric charge in laser fields**'' (CM&MA), Roum. J. Phys. **62** 117 (2017)

10)''**Scattering** of non-relativistic charges by electromagnetic radiation'' (MA) Z. Naturforsch. **A72** 1173 (2017)

11)''**Fast atom ionization** in strong electromagnetic radiation'' (MA) - 2017

12)''Electromagnetic-radiation effect on **alpha decay**'' (MA) - 2017

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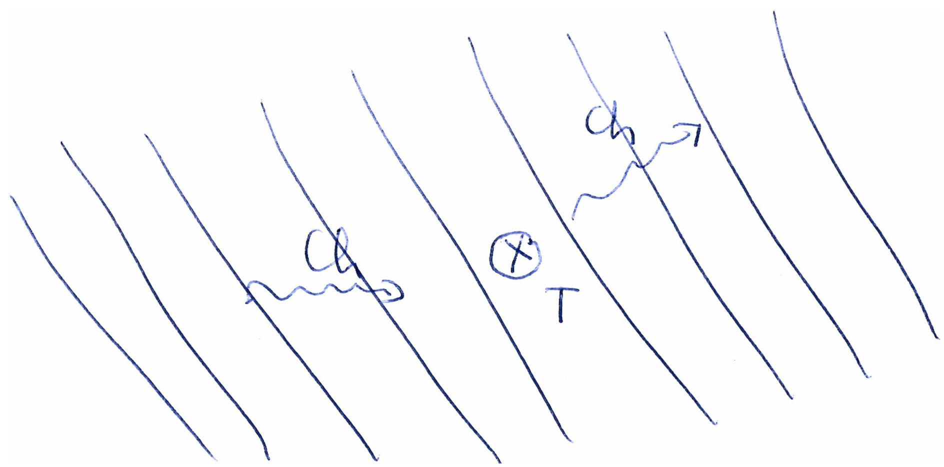
Magurele-Bucharest

Charges Scattered by Laser Pulses

M Apostol

2018

Charge Scattering Immersed in Radiation



Charge Scattering Immersed in Radiation

-Kroll-Watson (1973)

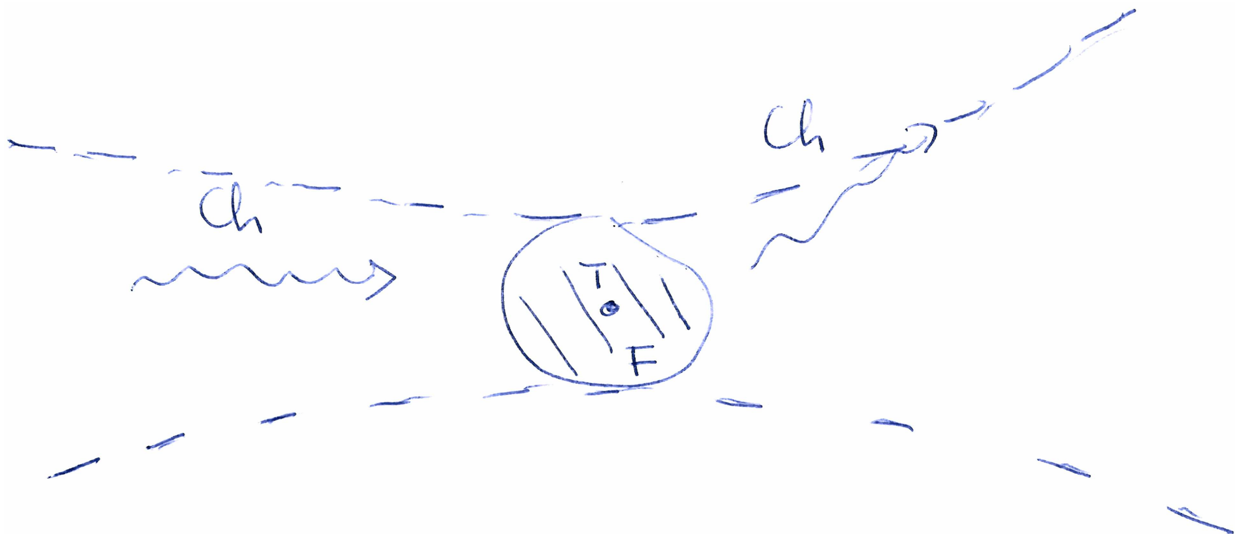
$$d\sigma_n = \frac{p_{fn}}{p_i} J_n^2(e\mathbf{p}\mathbf{E}_0/m\hbar\omega^2) d\sigma_B$$

$$\mathbf{p} = \mathbf{p}_i - \mathbf{p}_f \ , \ p_{fn}^2/2m = p_i^2/2m + n\hbar\omega$$

$$\theta_n \simeq \frac{\hbar\omega^2}{ev_i E_0}\alpha_n$$

-Low fields; importance: multiple photons

Focused Beams



-mainly heavy ions, electrons

Scattering in Focused Beams

-non-rel particle, mass m, charge e; em field $\mathbf{A} = \mathbf{A}_0 \cos(\omega t - \mathbf{kr})$ (lin pol)

-approx $\mathbf{A} \simeq \mathbf{A}_0 \cos \omega t$, $\mathbf{E}(t) = \mathbf{E}_0 \sin \omega t$, $\mathbf{E}_0 = \omega \mathbf{A}_0 / c$

-dipole hamiltonian

$$H = \frac{1}{2m} p^2 - e\mathbf{r}\mathbf{E}(t) + V(\mathbf{r})$$

- $eA_0/mc^2 \ll 1$; satisfied for heavy ions, strong fields

Schrodinger Equation

$$i\hbar\frac{\partial\psi_i}{\partial t} = (H_0 + U + V)\psi_i \ , \ U = -e\mathbf{r}\mathbf{E}(t)$$

-Incoming, outgoing states

$$\psi_i^0 = \frac{1}{\sqrt{v}}e^{-\frac{i}{\hbar}E_i t + \frac{i}{\hbar}\mathbf{p}_i\mathbf{r}} \ , \ \psi_f = \frac{1}{\sqrt{v}}e^{-\frac{i}{\hbar}E_f t + \frac{i}{\hbar}\mathbf{p}_f\mathbf{r}}$$

-Solution

$$\psi_i = \psi_i^0 - \frac{i}{\hbar}e^{-\frac{i}{\hbar}H_0 t}\int_{-\infty}^{t} dt' e^{\frac{i}{\hbar}H_0 t'}\,(U+V)\,\psi_i$$

-Scatt amplitude (S-matrix)

$$a_{fi} = -\frac{i}{\hbar}\int_{-\infty}^{+\infty} dt(\psi_f, (U+V)\psi_i)$$

Canonical Transformations

-GM

$$\psi_i = e^{iS_1}\phi_i \ , \ \ S_1 = -\frac{e}{\hbar c}\mathbf{r}\mathbf{A}$$

$$i\hbar\frac{\partial \phi_i}{\partial t} = \left[\frac{1}{2m}(\mathbf{p} - \frac{e}{c}\mathbf{A})^2 + V\right]\phi_i$$

-KH

$$\phi_i = e^{iS_2}\chi_i \ , \ \ S_2 = \frac{e}{\hbar m c\omega}\mathbf{p}\mathbf{A}_0 \sin \omega t - \frac{e^2}{8\hbar m c^2 \omega}A_0^2(\sin 2\omega t + 2\omega t)$$

$$i\hbar\frac{\partial \chi_i}{\partial t} = \left(H_0 + \widetilde{V}\right)\chi_i \ , \ \ \widetilde{V}(\mathbf{r}) = V(\mathbf{r} - e\mathbf{E}/m\omega^2)$$

-For V - Born approximation; consequently

$$\chi_i = \psi_i^0 - \frac{i}{\hbar} e^{-\frac{i}{\hbar}H_0 t} \int_{-\infty}^{t} dt' e^{\frac{i}{\hbar}H_0 t'} \widetilde{V} \psi_i^0$$

$$a_{fi} = -\tfrac{i}{\hbar} \int_{-\infty}^{+\infty} dt (\psi_f, (U+V) e^{iS_1} e^{iS_2} \psi_i^0) +$$

$$+ \left(-\tfrac{i}{\hbar}\right)^2 \int_{-\infty}^{+\infty} dt (\psi_f, U e^{iS_1} e^{iS_2} e^{-\frac{i}{\hbar}H_0 t} \int_{-\infty}^{t} dt' e^{\frac{i}{\hbar}H_0 t'} \widetilde{V} \psi_i^0)$$

-Three obs: laser scatt (U), $\widetilde{V}$ is rad-dressed, interf terms

Simplifications

-S_1: order $(r/\lambda)(eA_0/\hbar\omega) \gg eA_0/\hbar\omega$ ($E_0 = 10^8 esu$, $I = 10^{18} w/cm^2$, $eA_0 = 10^6 eV$)

-S_2: order $(p/mc\,, eA_0/mc^2)(eA_0/\hbar\omega) \ll eA_0/\hbar\omega$

-consequently, we may neglect S_2

-$\widetilde{V}$: order $r - \lambda_c(eA_0/\hbar\omega)$, very large ($\lambda_c = \hbar/mc$ Compton, $3 \times 10^{-11} cm$); neglect $\widetilde{V}$

Scatt Amplitude

$$a_{fi} = \frac{1}{v} \int_{-\infty}^{+\infty} dt d\mathbf{r} e^{\frac{i}{\hbar}(E_f - E_i)t} \frac{\partial}{\partial t} e^{-\frac{ie}{\hbar\omega}\mathbf{r}\mathbf{E}_0 \cos\omega t} e^{\frac{i}{\hbar}\mathbf{p}\mathbf{r}} -$$

$$-\frac{i}{\hbar v} \int_{-\infty}^{+\infty} dt d\mathbf{r} e^{\frac{i}{\hbar}(E_f - E_i)t} V e^{-\frac{ie}{\hbar\omega}\mathbf{r}\mathbf{E}_0 \cos\omega t} e^{\frac{i}{\hbar}\mathbf{p}\mathbf{r}}$$

- mom transfer $\mathbf{p} = \mathbf{p}_i - \mathbf{p}_f$

-Use

$$e^{-\frac{ie}{\hbar\omega}\mathbf{r}\mathbf{E}_0 \cos\omega t} = \sum_{n=-\infty}^{+\infty} (-i)^n J_n(e\mathbf{r}\mathbf{E}_0/\hbar\omega) e^{-in\omega t}$$

$$a_{fi} = -\frac{2\pi i}{v} \sum_{n=-\infty}^{+\infty} (-i)^n \delta(E_f - E_i - n\hbar\omega) \cdot$$

$$\cdot \int d\mathbf{r} \left[n\hbar\omega + V(\mathbf{r}) \right] J_n(e\mathbf{r}\mathbf{E}_0/\hbar\omega) e^{\frac{i}{\hbar}\mathbf{p}\mathbf{r}}$$

Cross-Section

-Trans prob

$$w_{fi} = \frac{2\pi}{\hbar v^2} \sum_{n=-\infty}^{+\infty} \delta(E_f - E_i - n\hbar\omega) \cdot$$

$$\cdot \left| \int d\mathbf{r} \, [n\hbar\omega + V(\mathbf{r})] \, J_n(e\mathbf{r}\mathbf{E}_0/\hbar\omega) e^{\frac{i}{\hbar}\mathbf{p}\mathbf{r}} \right|^2$$

-Multiply by density of fin sts $v p_f^2 dp_f d\Omega/(2\pi\hbar)^3$

-Divide by the current density v_i/v

-Integrate over the final mom p_f

-Get diff cross-section for the n-process

$$d\sigma_n = \frac{p_{fn}}{p_i} \left| \frac{m}{2\pi\hbar^2} \int d\mathbf{r} \, [n\hbar\omega + V(\mathbf{r})] \, J_n(e\mathbf{r}\mathbf{E}_0/\hbar\omega) e^{\frac{i}{\hbar}\mathbf{p}\mathbf{r}} \right|^2 d\Omega$$

-energy conservation $p_{fn}^2/2m = p_i^2/2m + n\hbar\omega$

Relation to Kroll-Watson

We remove S_2 and keep S_1 - KW keep S_2 and has not S_1

KW slow modulation of the Born ampl - we get a strong modulation (well-separated diffraction max)

Comments

-En cons $p_{fn}^2/2m = p_i^2/2m + n\hbar\omega$; (mom cons!), $\mathbf{p}$ along $\mathbf{E}_0$ ($\mathbf{p} \simeq e\mathbf{E}_0/\omega$)

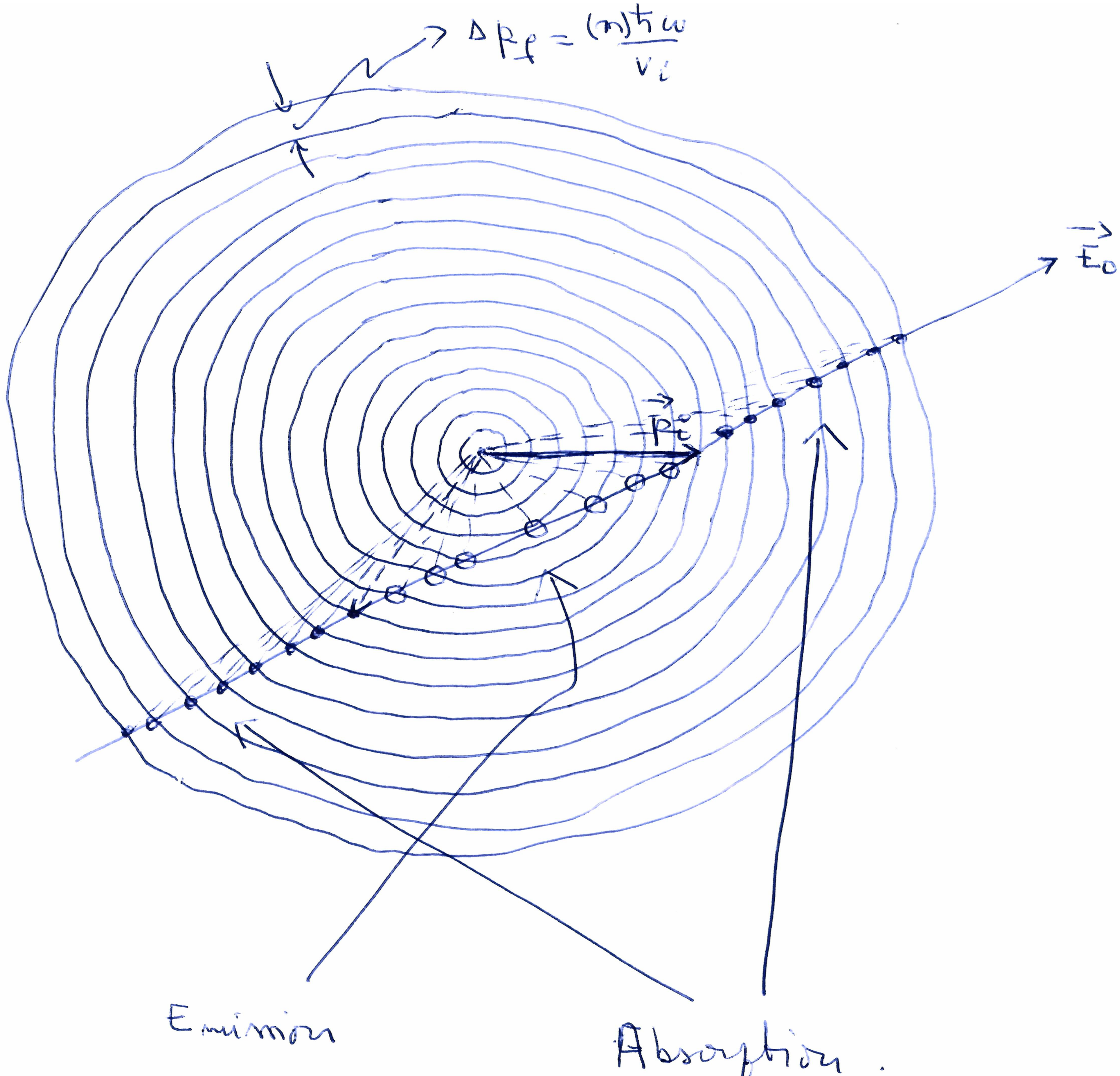
-Elastic scatt for $n = 0$

-Cons laws:

$$\theta_n \simeq \sin(\mathbf{p}_i, \mathbf{E}_0)\frac{n\hbar\omega}{2E_i}$$

-Photon absorption ($n > 0$), scatt angle θ_n increases, photon emiss ($n < 0$), θ_n decreases

-Favoured almost transverse, low fields, both forward & "backward" scatt (small n)


$\Delta p_f = \frac{(n)\hbar\omega}{v_i}$
$\vec{E_0}$
$\vec{p_i}$
Emission
Absorption

Order of magnitude

(In order to compute $\sigma_n$use the gen fct of J_n!)

$\sigma_n \simeq d^2[\frac{n\hbar\omega}{\hbar^2/md^2}]^2(\frac{\hbar\omega}{eE_0 d})^2$; for $d = 1\mu m$, $\omega = 10^{15}s^{-1}$, $E_0 = 10^8 esu$ ($I = 10^{18}w/cm^2$) cross-section $\sigma_n \simeq 10^{-2}n^2A^2(cm^{-2})$, heavy ions (small n, forward scatt)

-reduction $(a/d)^4 \simeq 10^{-16}$ (normaliz wavefunction, trajectory)

-electrons, favoured

Final obs

-Duration τ, repetition time Δt

-Reduction factor $\tau/(\tau + \Delta t)$