Emission of energetic electrons in fast ion-atom collisions assisted by a laser field

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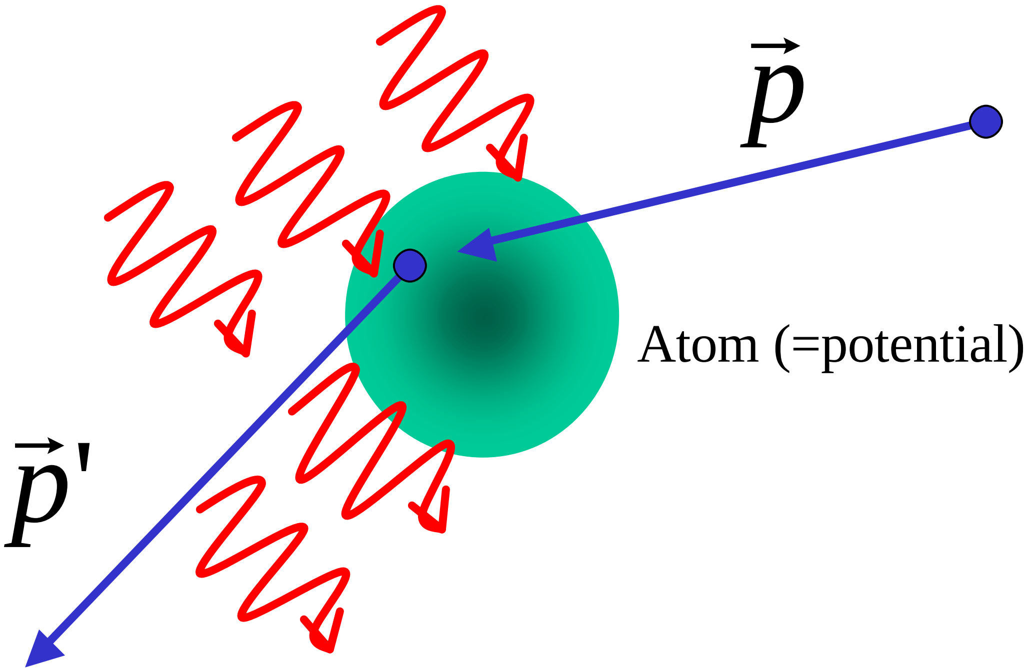
Field-assisted electron-atom scattering (free-free scattering)



$$ds = \sum_n ds_n$$

$$ds_n = \frac{p'}{p} J_n^2(b)\, ds_{el}$$

$$b = \frac{\vec{F}_0 \Delta\vec{p}}{w_0^2}$$

$$\Delta\vec{p} = \vec{p} - \vec{p}\,'$$

$$\frac{p^2}{2} = \frac{p'^2}{2} + n w_0$$

Fast Ion-Atom Collisions

$$v_p >> v_0$$

v_p – collision velocity

v_0 - typical orbiting velocity

Processes with high momentum transfer

I. Ionization

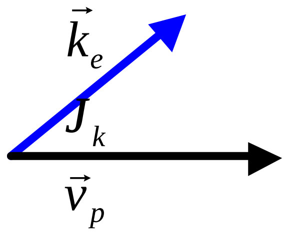
1.Capture to the projectile continuum

$$\vec{k}_e \approx \vec{v}_p, \Delta\vec{p} \approx \vec{v}_p, |\Delta\vec{p}| >> v_0$$

2.Binary-encounter emission

$$k_e = 2v_p \cos J_k$$

$$|\Delta\vec{p}| \approx 2v_p \cos J_k$$

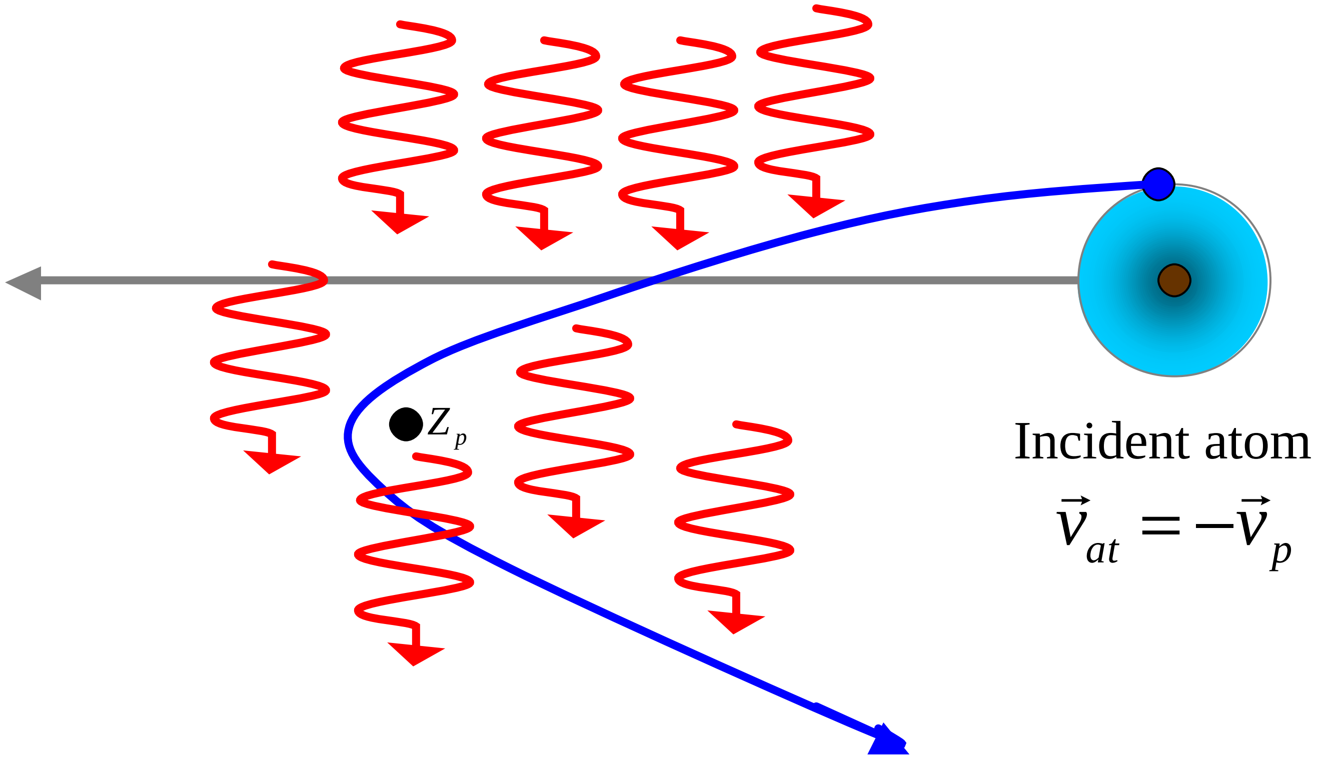


II. Charge exchange

Coulomb and radiative capture

$$\Delta\vec{p} \approx \vec{v}_p$$

Field-assisted binary emission (bound-free scattering)



1) $v >> Z_t$
2) $v >> Z_p (v > Z_p)$
3) $F_0 << F_{at}$
4) $w_0 << w_{at}$
5) No multiphoton resonances in the target

The field effect on free target is negligible provided 3)-5) are fulfilled

First order approximation in the projectile-target interaction

$$Z_p << v_p, Z_p << \left| \vec{k}_e - \vec{v}_p \right| \approx v_p$$

$$a_{fi} = -i \int_{-\infty}^{+\infty} dt < \Psi_f(t) | W_{\text{int}} | \Psi_i(t) >$$

$$W_{\text{int}} = -\frac{Z_p}{|\vec{R} - \vec{r}|}$$

$$i \frac{\partial \Psi_{i,f}}{\partial t} = (H_t + H_{\text{int}}) \Psi_{i,f}$$

$$H_t = -\frac{\Delta}{2} - \frac{Z_t}{r}$$

$$H_{\text{int}} = \frac{1}{c} \vec{A}(t) \vec{p} + \frac{A^2(t)}{2c^2}$$

$$\vec{A}(t) = \frac{\vec{F}_{01}}{w_0} \cos(w_0 t) + \frac{\vec{F}_{02}}{w_0} \cos(w_0 t + p / 2)$$

$$\vec{F}_{01} \vec{F}_{02} = 0$$

$$\vec{F}(t) = -\frac{1}{c} \frac{\partial \vec{A}}{\partial t}$$

Cross section

$$a = \sqrt{\left(\frac{\vec{F}_{01}\vec{k}}{w_0^2}\right)^2 + \left(\frac{\vec{F}_{02}\vec{k}}{w_0^2}\right)^2}$$

$$b = \sqrt{\left(\frac{\vec{F}_{01}\vec{r}}{w_0}\right)^2 + \left(\frac{\vec{F}_{02}\vec{r}}{w_0}\right)^2}$$

$$\frac{k}{w_0} >> r \propto 1 \Rightarrow a >> b$$

$$a w_0 >> \frac{F_{01}^2 + F_{01}^2}{w_0^2}$$

$$\frac{ds}{d\vec{k}} = \sum_{n=-\infty}^{n=+\infty} J_n^2\left(a(\vec{k})\right)\frac{ds_n}{d\vec{k}}$$

$$\frac{ds_n}{d\vec{k}} = \frac{4Z_p^2}{v_p^2}\int d^2\vec{Q}\frac{|<y_k|\exp(i(\vec{q}_n - \vec{p}_n)\vec{r})|y_0>|^2}{\vec{q}_n^4}$$

$$\vec{q}_n = \left(\vec{Q}; \frac{E_k + n w_0 - E_0}{v_p}\right)$$

$$\vec{p}_n = \frac{\left(\vec{F}_{01}\vec{k}\right)\vec{F}_{01} + \left(\vec{F}_{02}\vec{k}\right)\vec{F}_{02}}{\left(\vec{F}_{01}\vec{k}\right)^2 + \left(\vec{F}_{02}\vec{k}\right)^2} n w_0$$

Typical number of exchanged photons

$$|n_{\max}| \approx a = \sqrt{\left(\frac{\vec{F}_{01}\vec{k}}{w_0^2}\right)^2 + \left(\frac{\vec{F}_{02}\vec{k}}{w_0^2}\right)^2}$$

Typical amount of exchanged energy

$$\Delta E \approx a w_0$$

Linear polarization
Comparison of „bound-free“ and free-free transitions

$$\vec{F}_{01} = \vec{F}_0, \vec{F}_{02} = 0$$

$$a = \frac{\left|\vec{F}_0 \vec{k}\right|}{w_0^2}$$

$$a w_0 >> \frac{F_0^2}{w_0^2}$$

$$\frac{ds}{d\vec{k}} = \frac{4Z_p^2}{v_p^2} \sum_n J_n^2(a) \int d^2\vec{Q} \frac{\left|\left\langle y_k \right| \exp(i(\vec{q}_n - \vec{p}_n)\vec{r}) \left| y_0 \right\rangle\right|^2}{\vec{q}_n^4}$$

$$\vec{q}_n = \left(\vec{Q}; \frac{E_k + n w_0 - E_0}{v_p} \right); \vec{p}_n = \frac{\vec{F}_0}{w_0} \frac{n}{a}$$

Free-free transitions:

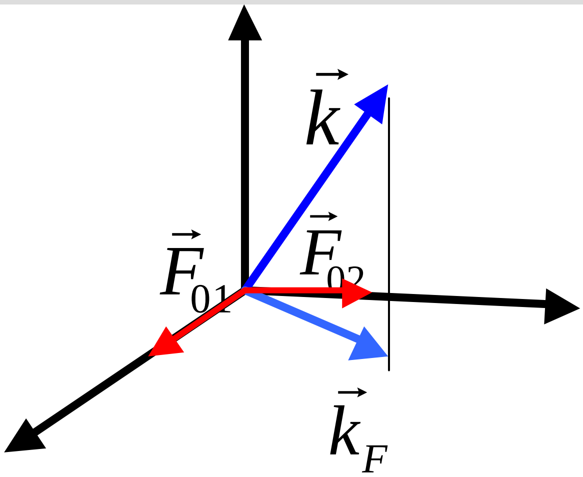
$$ds = \sum_n \frac{p'}{p} J_n^2(b) ds_{el}$$

$$b = \left| \frac{\vec{F}_0 \Delta \vec{p}}{w_0^2} \right|$$

Circular polarization

$$|\vec{F}_{01}| = |\vec{F}_{02}| = F_0$$

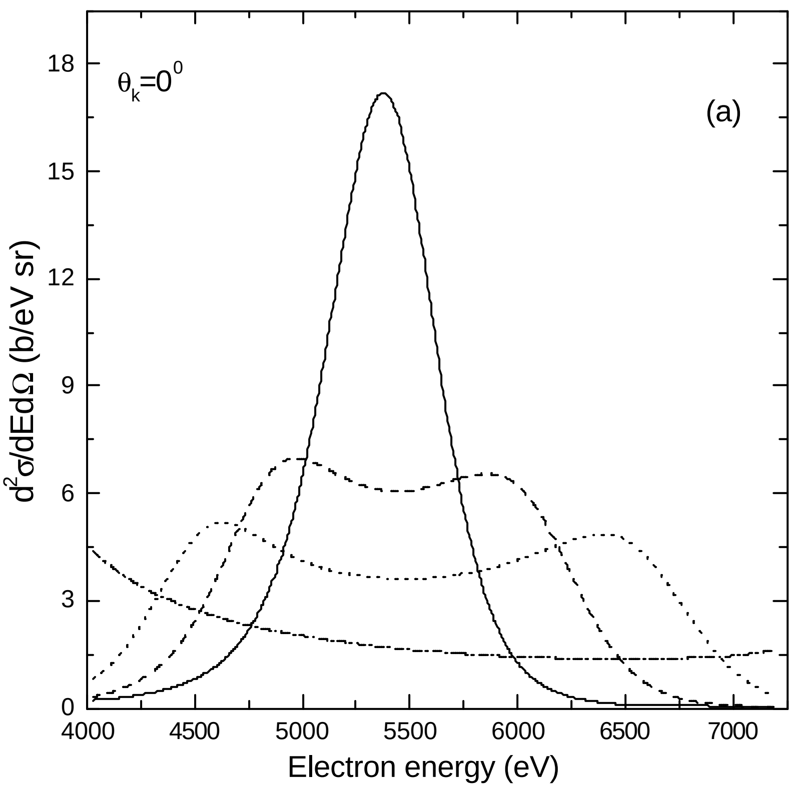
$$a = \frac{F_0 k_F}{w_0^2}$$



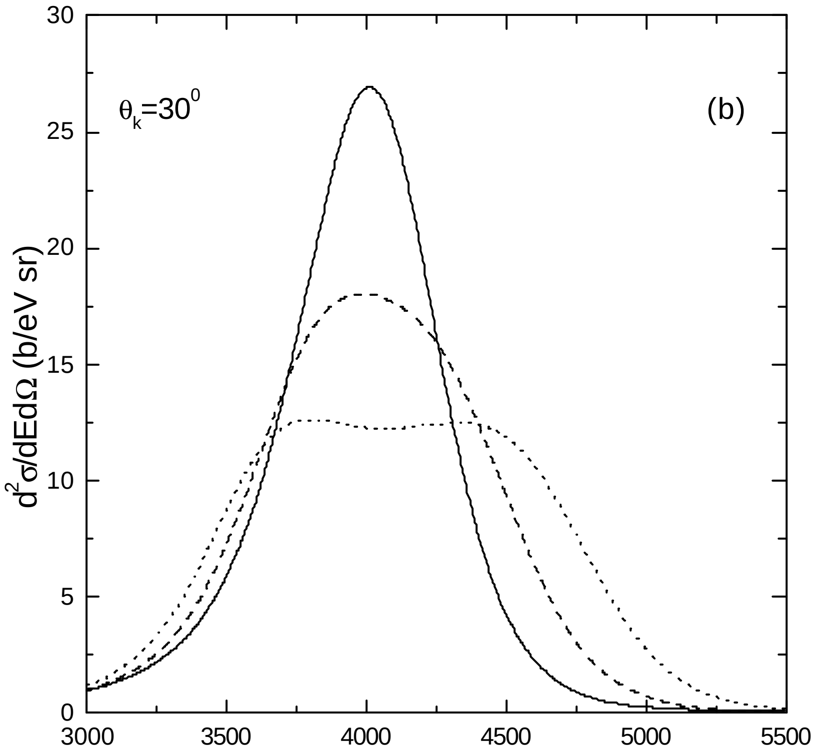
$$\frac{ds}{d\vec{k}} = \frac{4Z_p^2}{v_p^2} \sum_n J_n^2(a) \int d^2\vec{Q} \frac{\left| \langle y_k | \exp(i(\vec{q}_n - \vec{p}_n)\vec{r}) | y_0 \rangle \right|^2}{\vec{q}_n^4}$$

$$\vec{q}_n = \left(\vec{Q}; \frac{E_k + nw_0 - E_0 + F_0^2/(2w_0^2)}{v_p} \right)$$

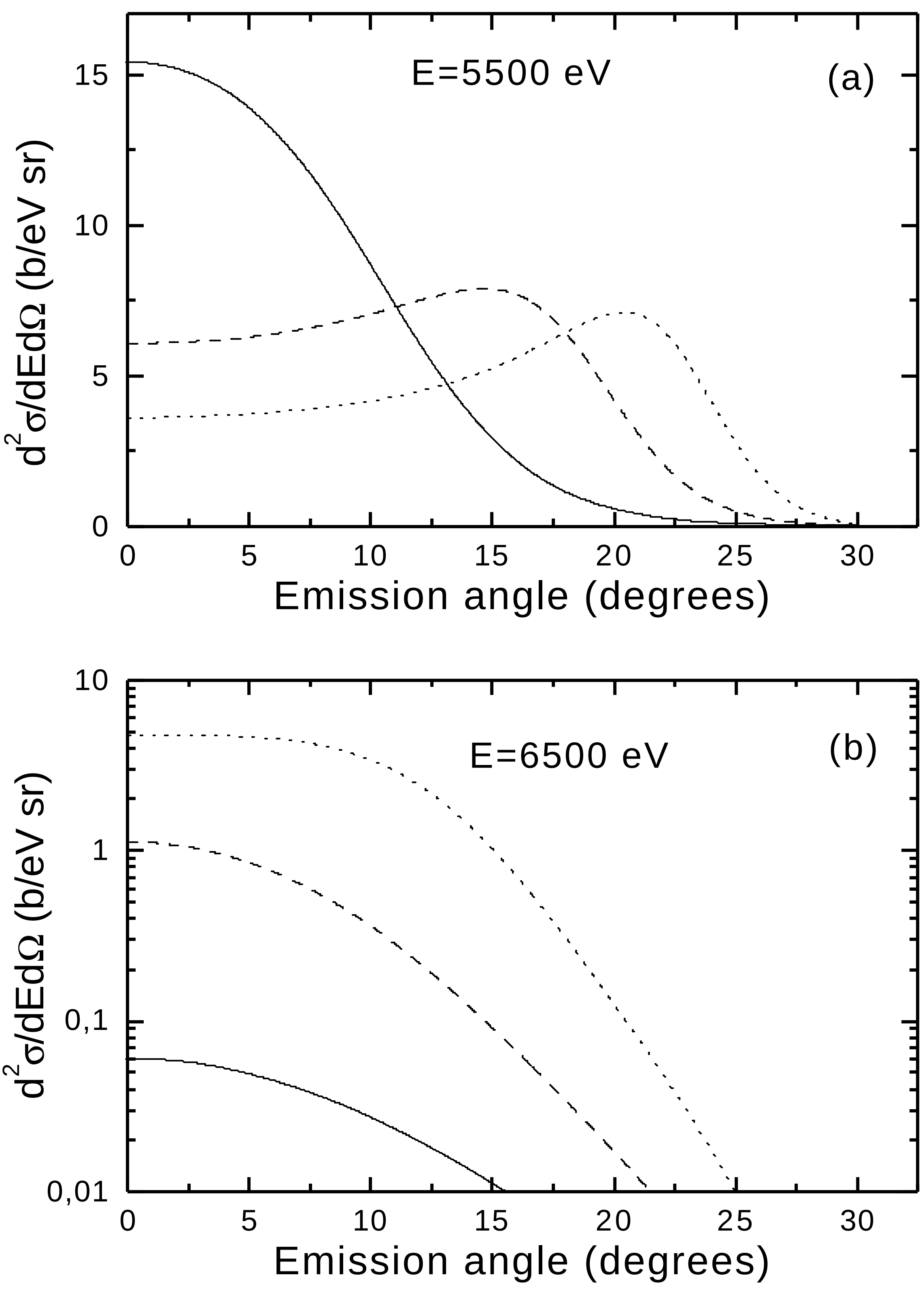
$$\vec{p}_n = \frac{(\vec{F}_{01}\vec{k})\vec{F}_{01} + (\vec{F}_{02}\vec{k})\vec{F}_{02}}{(\vec{F}_{01}\vec{k})^2 + (\vec{F}_{02}\vec{k})^2} nw_0$$



θk=0°
(a)
d²σ/dEdΩ (b/eV sr)
Electron energy (eV)
0
3
6
9
12
15
18
4000
4500
5000
5500
6000
6500
7000



θk=30°
(b)
d²σ/dEdΩ (b/eV sr)
Electron energy (eV)
0
5
10
15
20
25
30
3000
3500
4000
4500
5000
5500



E=5500 eV
(a)
$d^2\sigma/dEd\Omega$ (b/eV sr)
Emission angle (degrees)
E=6500 eV
(b)
$d^2\sigma/dEd\Omega$ (b/eV sr)
Emission angle (degrees)

FIG.2

Conclusion

- 1. A relatively weak low-frequency field may have a profound effect on the „binary-encounter“ emission.
- 2. This effect can be interpreted as due to the exchange of a huge number of photons between the colliding system and the field that results in a large energy exchange between the electron and the field.
- 3. The structure of the „bound-free“ electron scattering have certain similarity to that of the free-free scattering.
- 4. At the same time these two processes have very important differences which reflect the different nature of a bound and a free electron, in particular their different response to the action of a weak low-frequency field.