THE FEATURES OF TRANSITION AND CHERENKOV RADIATION OF MULTI-CHARGED IONS

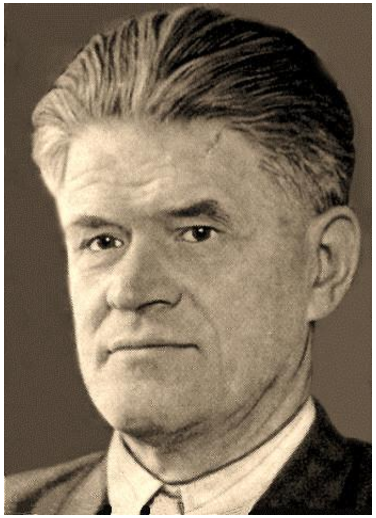
V.S. Malyshevsky, I.A. Ivanova

Southern Federal University, 344090, Rostov-on-Don, Russia
E-mail address: vsmalyshevsky@sfedu.ru

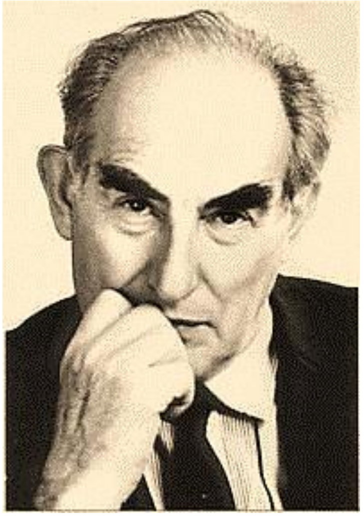
Nobel Prize Laureates. Discoverers of the Cherenkov and Transition radiation

I. Tamm

I. Frank



P. Cherenkov



V. Ginsburg

Radiation emitted by heavy multiply charged ions in the amorphous targets

Bremsstrahlung, Transition Radiation, Cherenkov Radiation

The main problems:

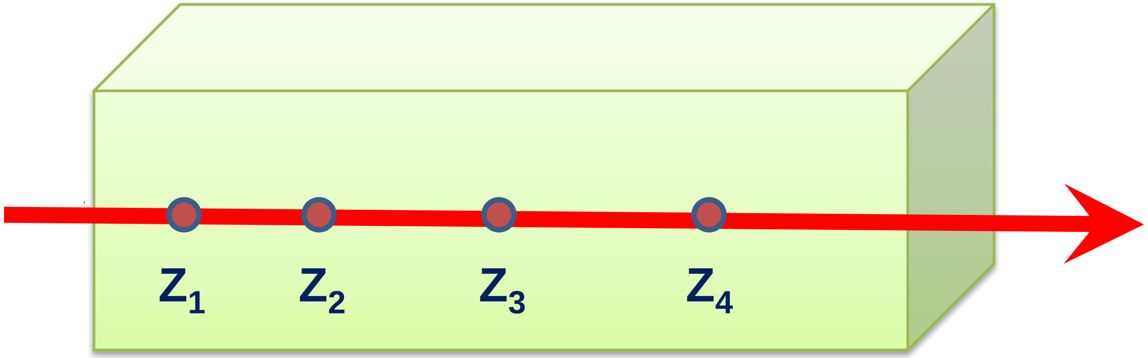
For heavy multiply charged ions we have to take into account the stopping power and charge exchange with the target.

!

In this report:

- Short review of charge exchange effects on the Cherenkov Radiation.
- Some expected effects of charge exchange in Transition Radiation.

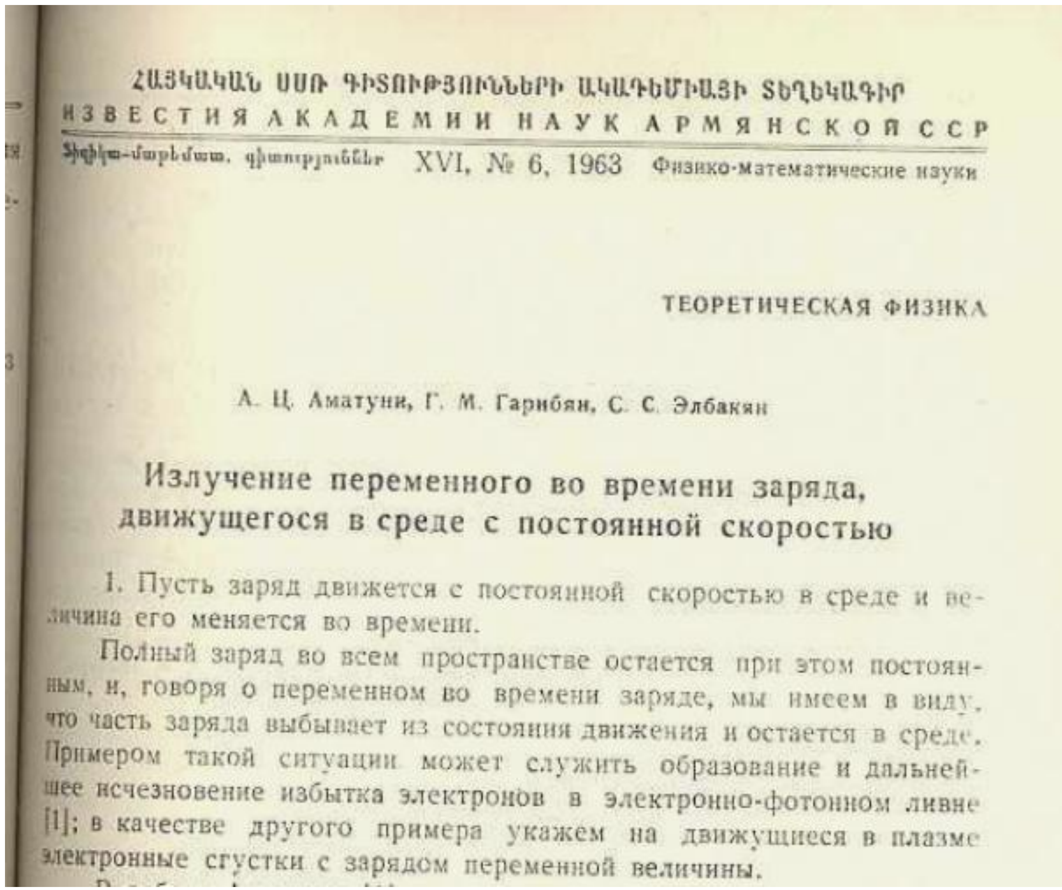
When heavy ions penetrate into the target, the ion-atom collisions cause fluctuations of the projectile charge due to electrons loss or capture.



$$Q(\mathbf{k},\omega) = \left< -\frac{1}{8\pi^4}\,\mathrm{Im}\left[\frac{4\pi}{\omega\varepsilon}\left|\mathbf{j}_{\parallel}\right|^2 + \frac{4\pi\omega}{c^2}\frac{\left|\mathbf{j}_{\perp}\right|^2}{\frac{\omega^2}{c^2}\varepsilon - \frac{k^2}{\mu}}\right]\right>$$

The radiation of a time-varying charge moving in a medium with a constant speed

Amatuni A.C., Garibyn G.M., Elbakyan S.S.
Proceedings of the Academy of Sciences of the Armenian SSR.
1963. T. XVI. №6. C. 101-112.


ՀԱՅԿԱԿԱՆ ՍՍՌ ԳԻՏՈՒԹՅՈՒՆՆԵՐԻ ԱԿԱԴԵՄԻԱՅԻ ՏԵՂԵԿԱԳԻՐ
ИЗВЕСТИЯ АКАДЕМИИ НАУК АРМЯНСКОЙ ССР

Ֆիզիկա-մաթեմատ. գիտություններ XVI, № 6, 1963 Физико-математические науки

ТЕОРЕТИЧЕСКАЯ ФИЗИКА

А. Ц. Аматуни, Г. М. Гарибян, С. С. Элбакян

Излучение переменного во времени заряда, движущегося в среде с постоянной скоростью

1. Пусть заряд движется с постоянной скоростью в среде и величина его меняется во времени.

Полный заряд во всем пространстве остается при этом постоянным, и, говоря о переменном во времени заряде, мы имеем в виду, что часть заряда выбывает из состояния движения и остается в среде. Примером такой ситуации может служить образование и дальнейшее исчезновение избытка электронов в электронно-фотонном ливне [1]; в качестве другого примера укажем на движущиеся в плазме электронные сгустки с зарядом переменной величины.

The correlation between various charge state values can arise in the Stopping Power, Bremsstrahlung, Transition and Cherenkov radiation

AUTOCORRELATION FUNCTION:

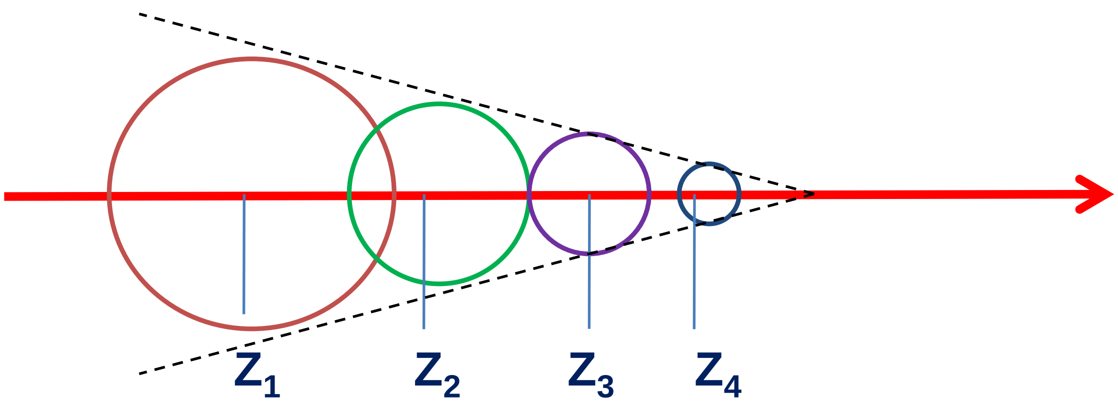
$$\left\langle Z(t)Z(t')\right\rangle = Z_{eq}^2 + \left\langle \xi(t)\xi(t')\right\rangle \quad \left\langle \xi(t)\xi(t')\right\rangle = \Lambda^2 \exp(-\Gamma\left|t-t'\right|)$$

LONGITUDINAL WAVES :

Z.I. Miskovic, S.G Davison., F.O Goodman., W.K. Liu Phys. Rev. 1999, B60, 14478-1483.

TRANSVERSE WAVES (HUYGENS PRINCIPLE**):**

V.S. Malyshevsky. Physics Letters, A372 (2008) 2133–2136



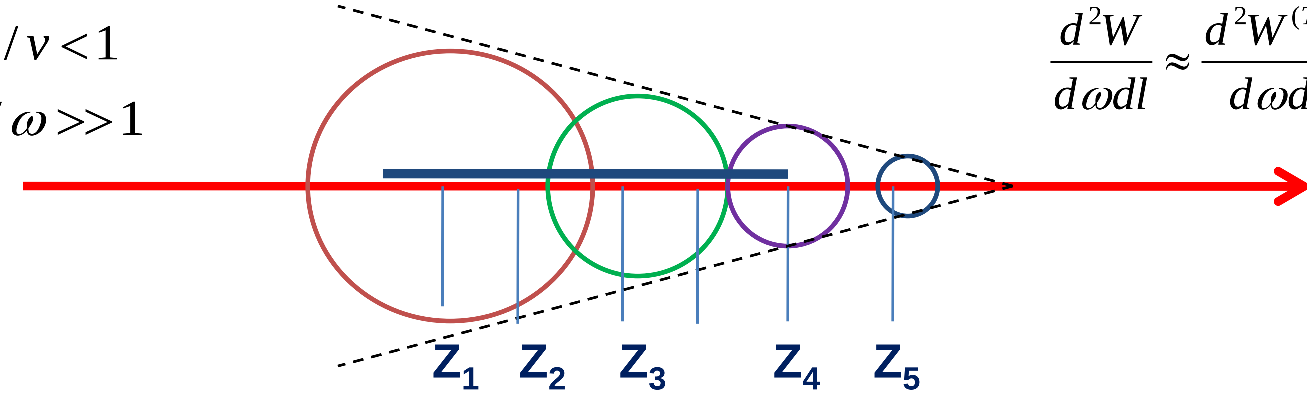
Correlation effects

The threshold condition is satisfied

V.S. Malyshevsky. Physics Letters, A372 (2008) 2133–2136

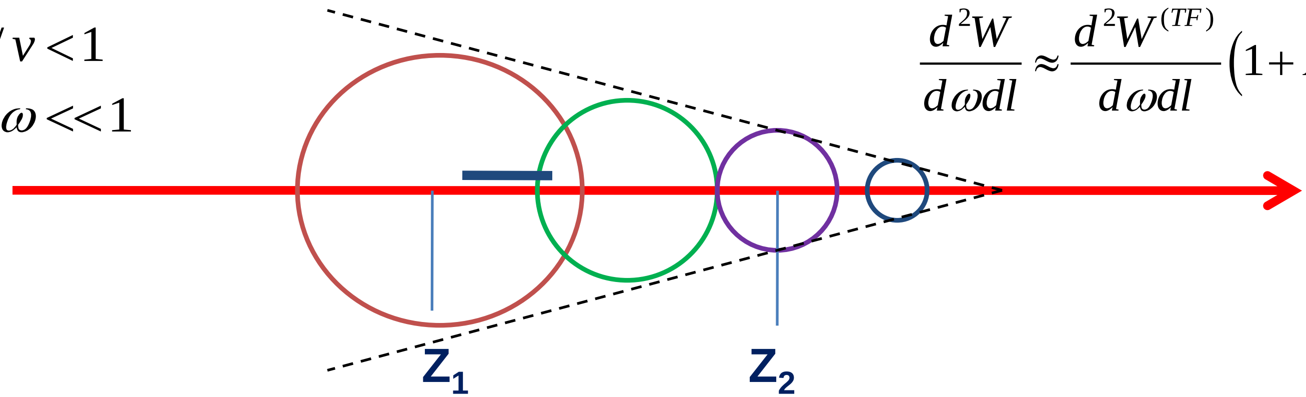
$$c_p / v < 1$$
$$\Gamma / \omega >> 1$$

$$\frac{d^2W}{d\omega dl} \approx \frac{d^2W^{(TF)}}{d\omega dl}$$



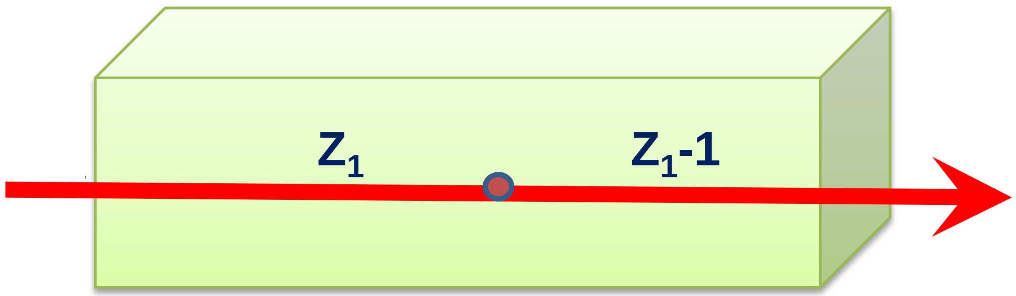
$$c_p / v < 1$$
$$\Gamma / \omega << 1$$

$$\frac{d^2W}{d\omega dl} \approx \frac{d^2W^{(TF)}}{d\omega dl}\left(1 + \Lambda^2 / Z_{eq}^2\right)$$



A single electron capture (loss)

V.S. Malyshevsky. Technical Physics Letters, 2014, Vol. 40, No. 4, pp. 320–322.



$v < c_p$

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2 v^2 \sqrt{\varepsilon'(\omega)} \sin^2\theta}{(2\pi)^2} \frac{1}{(1 - v\sqrt{\varepsilon'(\omega)}\cos\theta)^2}$$

$v > c_p$

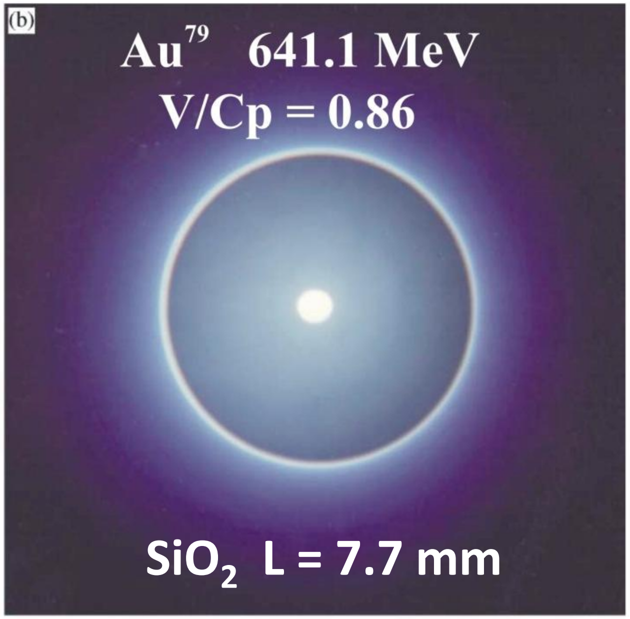
$$\frac{1}{L}\frac{d^2W}{d\omega d\Omega} = \frac{\omega^2 v e^2 \sqrt{\varepsilon'(\omega)} \sin^2\theta}{2\pi} (Z_1 - 1/2)^2 \delta(\omega - \mathbf{kv}).$$

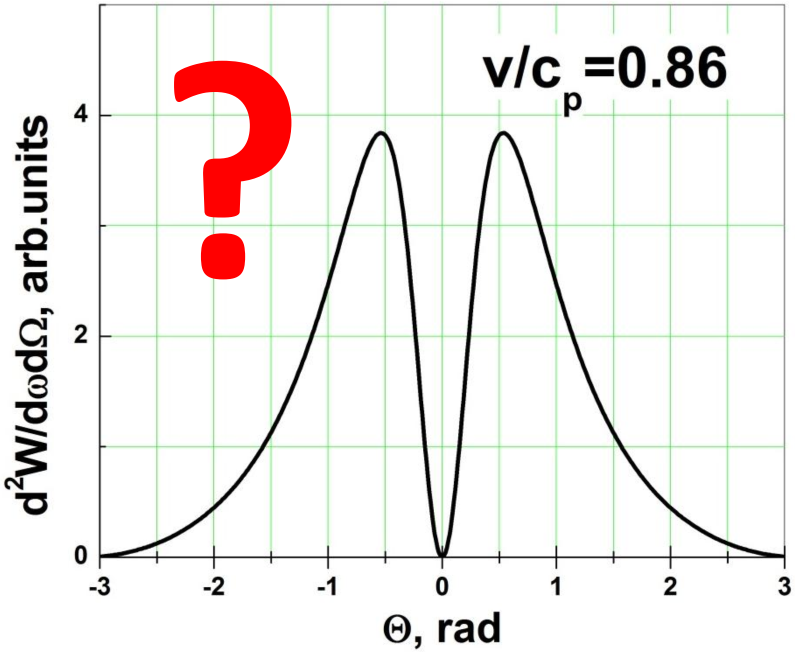
"Average" charge $\left[Z_1 + (Z_1 - 1)\right]/2 = Z_1 - 1/2$

A single electron capture (loss)

J. Ruzicka et al. Vacuum 63 (2001) 591-595

The threshold condition is not satisfied





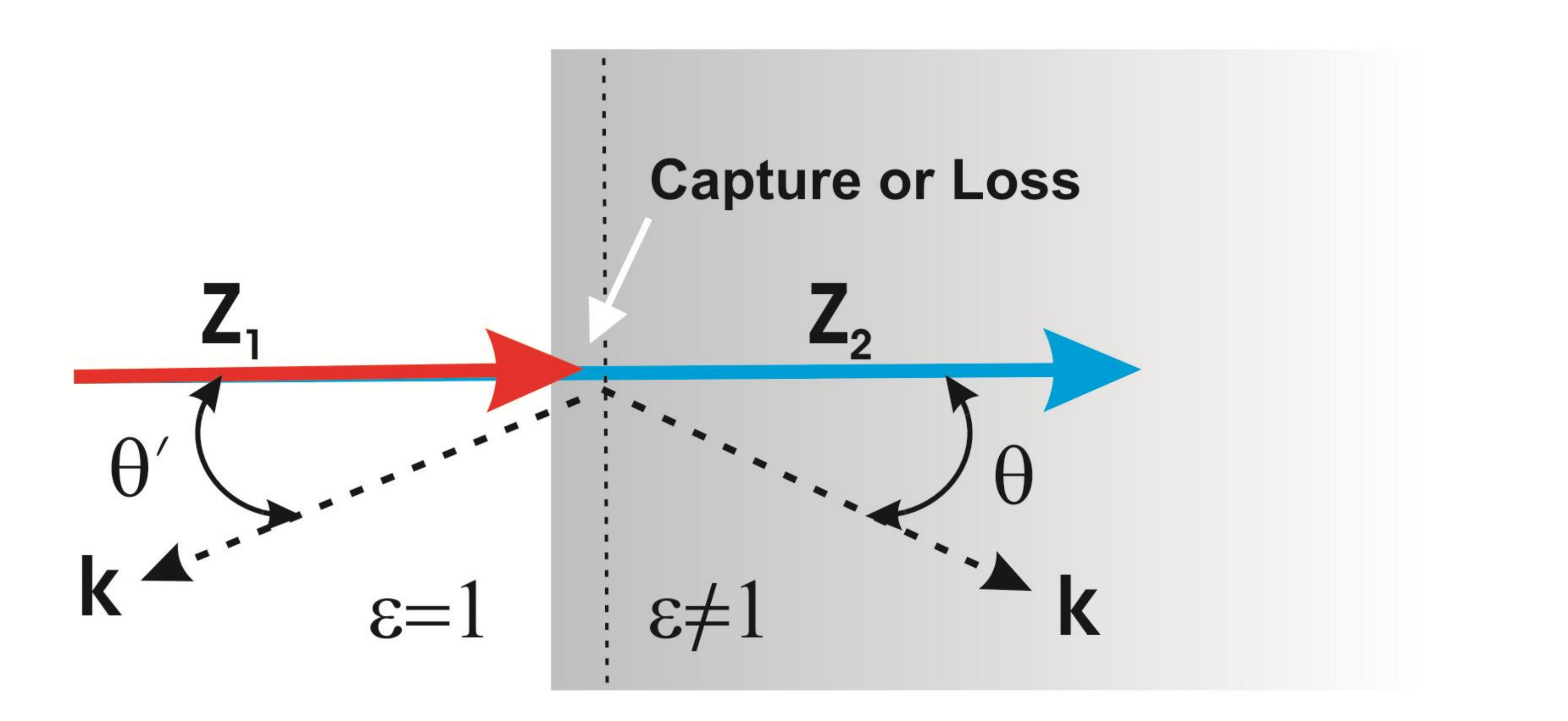
Capture probability ~ 1

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2 v^2 \sqrt{\varepsilon'(\omega)}\sin^2\theta}{(2\pi)^2}\frac{1}{(1 - v\sqrt{\varepsilon'(\omega)}\cos\theta)^2}$$

$$v < c_p$$

Transition radiation

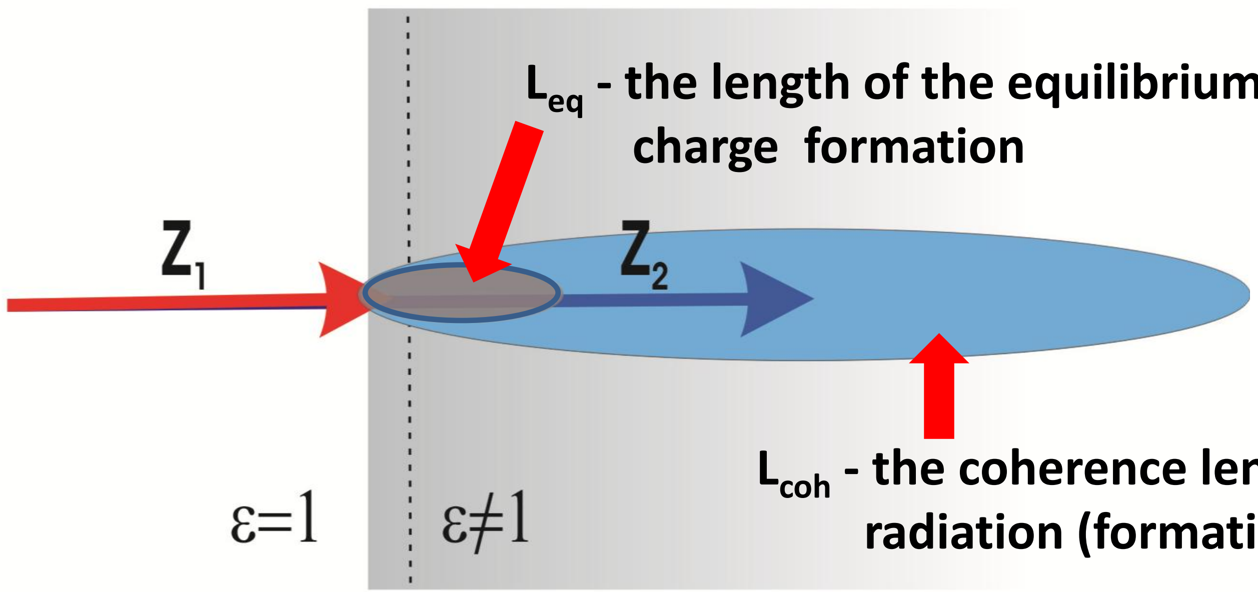
Formulation of the problem



Transition radiation

Basic approximation

$$L_{coh} >> L_{eq}$$



$$L_{eq} \approx 1/\sigma n_e$$

$$L_{coh} \approx \lambda \frac{\beta(1+\beta)}{1-\beta^2}$$

Transition radiation

Maxwell's equations in the first and second media

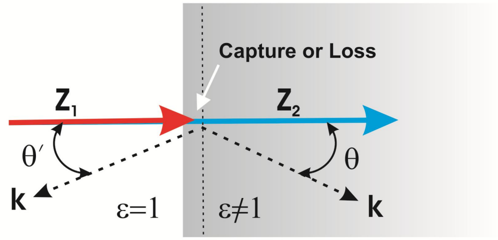
$$\Delta \mathbf{A} - \frac{1}{c^2}\frac{\partial^2 \mathbf{A}}{\partial^2 t} = -\frac{4\pi}{c} Z_1 e \mathbf{v} \delta(\mathbf{r} - \mathbf{v}t), \qquad \Delta\varphi - \frac{1}{c^2}\frac{\partial^2 \varphi}{\partial^2 t} = -4\pi Z_1 e \delta(\mathbf{r} - \mathbf{v}t).$$

$$\Delta \mathbf{A} - \frac{\varepsilon}{c^2}\frac{\partial^2 \mathbf{A}}{\partial^2 t} = -\frac{4\pi}{c} Z_2 e \mathbf{v} \delta(\mathbf{r} - \mathbf{v}t), \qquad \Delta\varphi - \frac{\varepsilon}{c^2}\frac{\partial^2 \varphi}{\partial^2 t} = -\frac{4\pi}{\varepsilon} Z_2 e \delta(\mathbf{r} - \mathbf{v}t).$$

Fields are found from the condition of continuity of normal and tangential components

Transition radiation

Spectral- angular density



Backward

$$\frac{d^2W_1}{d\omega d\Omega'} = \frac{e^2 \sin^2\vartheta' \cos^2\vartheta'}{\pi^2 c} \left| \frac{\beta}{\varepsilon\cos\vartheta' + \sqrt{\varepsilon - \sin^2\vartheta'}} F_1(\vartheta') \right|^2 ,$$

$$F_1(\vartheta') = \frac{Z_1(\varepsilon - \beta\sqrt{\varepsilon - \sin^2\vartheta'})}{1-\beta^2\cos^2\vartheta'} - \frac{Z_2}{1+\beta\sqrt{\varepsilon - \sin^2\vartheta'}} .$$

Forward

$$\frac{d^2W_2}{d\omega d\Omega} = \frac{e^2\varepsilon^{5/2} \sin^2\vartheta \cos^2\vartheta}{\pi^2 c} \left| \frac{\beta}{\cos\vartheta + \varepsilon^{1/2}\sqrt{1-\varepsilon\sin^2\vartheta}} F_2(\vartheta) \right|^2 ,$$

$$F_2(\vartheta) = \frac{Z_1}{1-\beta\sqrt{1-\varepsilon\sin^2\vartheta}} - \frac{Z_2(1+\beta\varepsilon\sqrt{1-\varepsilon\sin^2\vartheta})}{\varepsilon\left(1-\beta^2\varepsilon\cos^2\vartheta\right)} .$$

If $Z_1 = Z_2$ we obtain the well-known Ginsburg – Frank formulas

Transition radiation

Spectral- angular density in the special cases

If $Z_1 = 1$, $Z_2 = 0$, $\varepsilon \to \infty$ we obtain the backward Transition Radiation from metal surface:

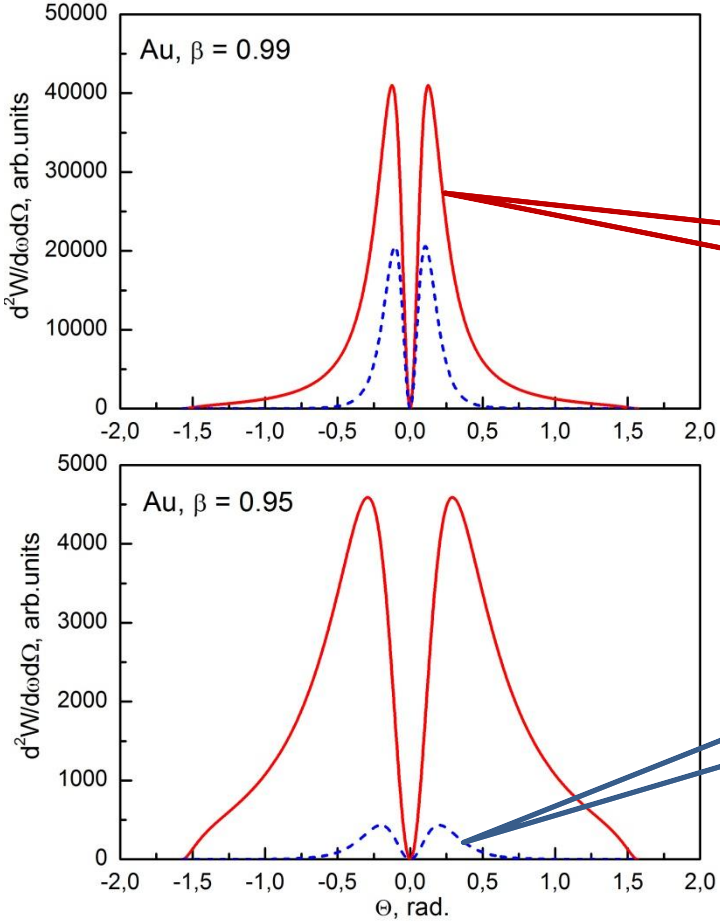
$$\frac{d^2W_1}{d\omega d\Omega'} = \frac{e^2 \sin^2 \vartheta'}{\pi^2 c} \frac{\beta^2}{\left(1-\beta^2 \cos^2 \vartheta'\right)^2}.$$

If $Z_1 = 0$, $Z_2 = 1$, $\varepsilon = 1$ we obtain the radiation of the electron which starts suddenly:

$$\frac{d^2W_{1,2}}{d\omega d\Omega} = \frac{e^2 \sin^2 \vartheta}{4\pi^2 c} \frac{\beta^2}{\left(1-\beta \cos \vartheta\right)^2}.$$

Transition radiation (some calculations)

Forward radiation in the vacuum ultraviolet



$$Z_2 / Z_1 = 1 - C \exp(-v / v_B Z_1^{\gamma})$$

H. Betz, Rev. Mod. Phys., **44**, 465 (1972).

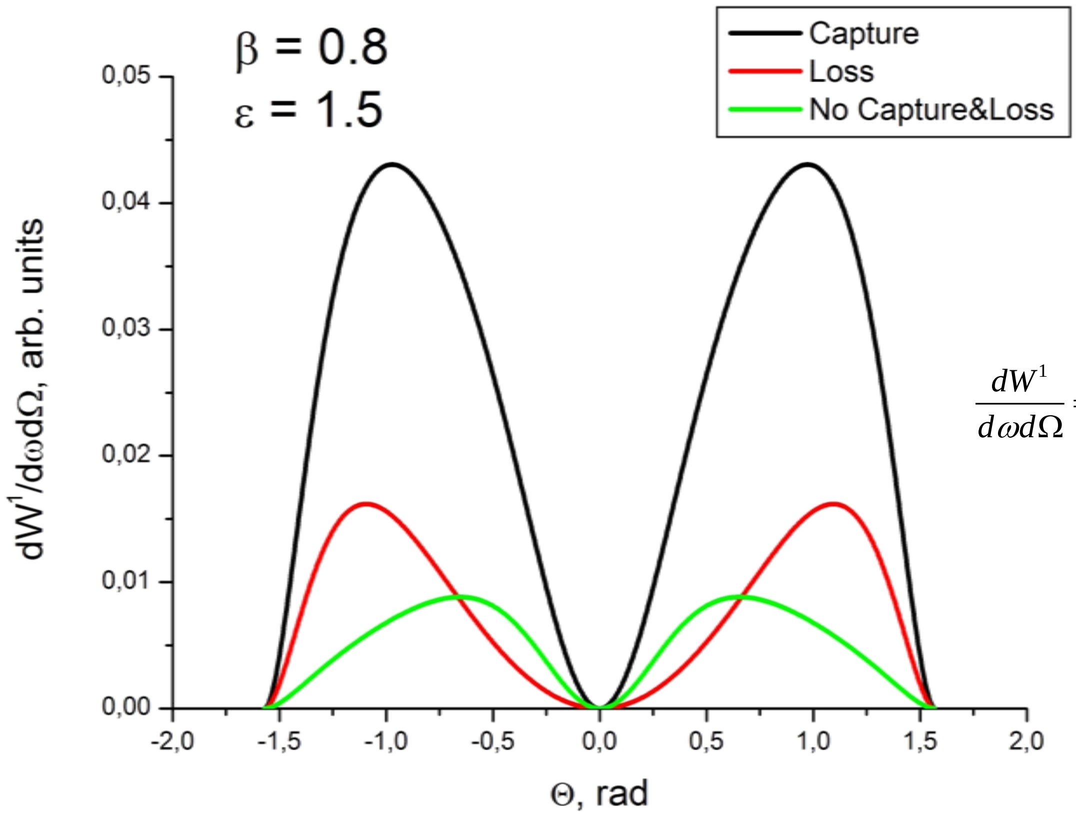
Transition radiation with charge exchange

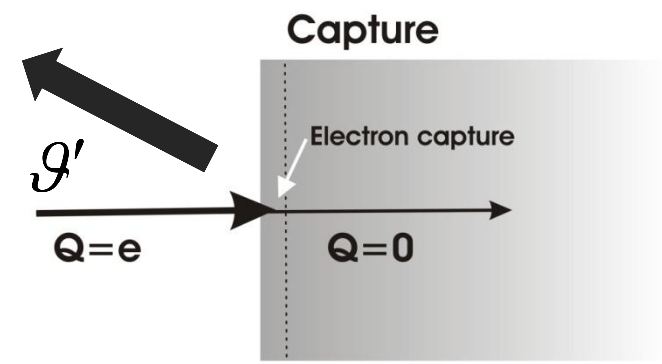
Ginsburg-Frank formula without charge exchange

Charge exchange in the medium increases the intensity of the Transition radiation

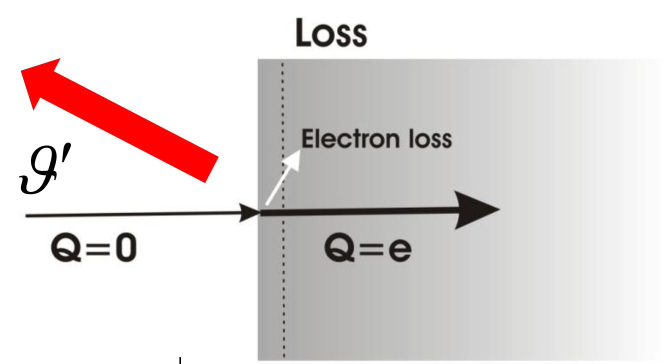
Transition radiation (some calculations)

Backward radiation in the optical range





$$\frac{dW^1}{d\omega d\Omega}=\frac{e^2\sin^2\vartheta'\cos^2\vartheta'}{\pi^2 c}\left|\frac{\beta\left(\varepsilon-\beta\sqrt{\varepsilon-\sin^2\vartheta'}\right)}{\left(\varepsilon\cos\vartheta'+\sqrt{\varepsilon-\sin^2\vartheta'}\right)\left(1-\beta^2\cos^2\vartheta'\right)}\right|^2$$



$$\frac{dW^1}{d\omega d\Omega}=\frac{e^2\sin^2\vartheta'\cos^2\vartheta'}{\pi^2 c}\left|\frac{\beta}{\left(\varepsilon\cos\vartheta'+\sqrt{\varepsilon-\sin^2\vartheta'}\right)\left(1+\beta\sqrt{\varepsilon-\sin^2\vartheta'}\right)}\right|^2$$

Thank you for your attention !