PHY 712 Electrodynamics
11-11:50 AM MWF Olin 107

Plan for Lecture 32:

Read material from Chap. 13 & 15

1. Cherenkov radiation
2. Bremsstrahlung

	03-20(Wed)	*APS Meeting*	(no class)	Exam
	03-22(Fri)	*APS Meeting*	(no class)	Exam
25	03-25(Mon)	Chap. 11	Lorentz transformations	#17
26	03-27(Wed)	Chap. 11	Transformations between electromagnetic fields	#18
27	03-28(Thur)	Chap. 11	Liénard-Wiechert potentials revisited	
	03-29(Fri)	*Good Friday*	(no class)	
28	04-01(Mon)	Chap. 14	Radiation by accelerated charges	#19
29	04-03(Wed)	Chap. 14	Radiation by accelerated charges	#20
30	04-05(Fri)	Chap. 14	Synchrotron radiation spectrum	#21
31	04-08(Mon)	Chap. 14	Synchrotron and other radiation sources	#22
32	04-10(Wed)	Chap. 15	Radiation due to collisions of charged particles	
33	04-12(Fri)	Chap. 15	Radiation due to energy loss processes	
	04-15(Mon)		(no class -- presentation preparation)	
	04-17(Wed)		(no class -- presentation preparation)	
	04-19(Fri)		(no class -- presentation preparation)	
34	04-22(Mon)			
35	04-24(Wed)			
36	04-26(Fri)			
	04-29(Mon)		Student presentations I	
	05-01(Wed)		Student presentations II	
	05-02(Thurs)		Student presentations III	

WFU Joint Chemistry and Physics Colloquium

TITLE: Sunlight-to-Fuel Energy Conversion Using Cu(I)-Containing Oxide Semiconductors

SPEAKER: Professor Paul A. Maggard,

Department of Chemistry,
North Carolina State University, Raleigh, North Carolina

TIME: Wednesday April 10, 2013 at 4:00 PM

PLACE: Room 101 Olin Physical Laboratory

Refreshments will be served at 3:30 PM in the Olin Lounge. All interested persons are cordially invited to attend.

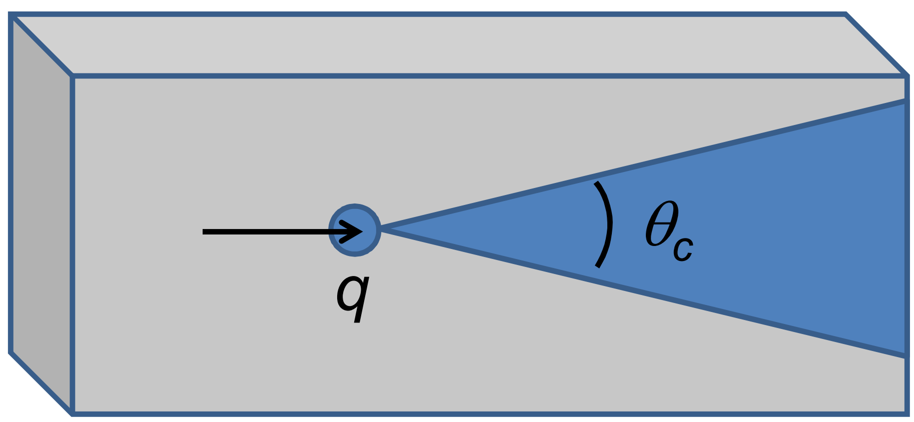
ABSTRACT

The conversion of solar energy to chemical fuels, e.g., the renewable production of hydrogen or methanol, has attracted intense research interest as both a practical and environmentally responsible way to meet our growing energy needs. The photoelectrochemical reduction of water to hydrogen can be facilitated using p-type semiconducting films, such as previously known for crystalline III-V semiconductors. Our research efforts focus on a promising new class of p-type semiconductors found in the Cu(I)-tantalate and Cu(I)-niobate systems, e.g., $CuNb_3O_8$ and $Cu_3Ta_7O_{19}$, that exhibit bandgap sizes spanning the visible-light energies. Measurements of their conduction-band energies show that these are located at suitable energies (from

References for notes: Glenn S. Smith, *An Introduction to Electromagnetic Radiation* (Cambridge UP, 1997), Andrew Zangwill, Modern Electrodynamics (Cambridge UP, 2013)

Cherenkov radiation

Discovered ~1930; bluish light emitted by energetic charged particles traveling within dielectric materials



Maxwell's potential equations within a material having permittivity and permeability (Lorentz gauge; cgs Gaussian units)

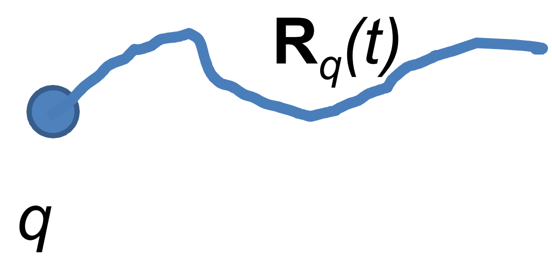
$$\nabla^2\Phi - \mu\varepsilon\frac{1}{c^2}\frac{\partial^2\Phi}{\partial t^2} = -\frac{4\pi}{\varepsilon}\rho$$

$$\nabla^2\mathbf{A} - \mu\varepsilon\frac{1}{c^2}\frac{\partial^2\mathbf{A}}{\partial t^2} = -\frac{4\pi\mu}{c}\mathbf{J}$$

Source: charged particle moving on trajectory $\mathbf{R}_q(t)$:

$$\rho(\mathbf{r},t) = q\delta(\mathbf{r} - \mathbf{R}_q(t))$$

$$\mathbf{J}(\mathbf{r},t) = q\dot{\mathbf{R}}_q(t)\delta(\mathbf{r} - \mathbf{R}_q(t))$$



Liénard-Wiechert potential solutions:

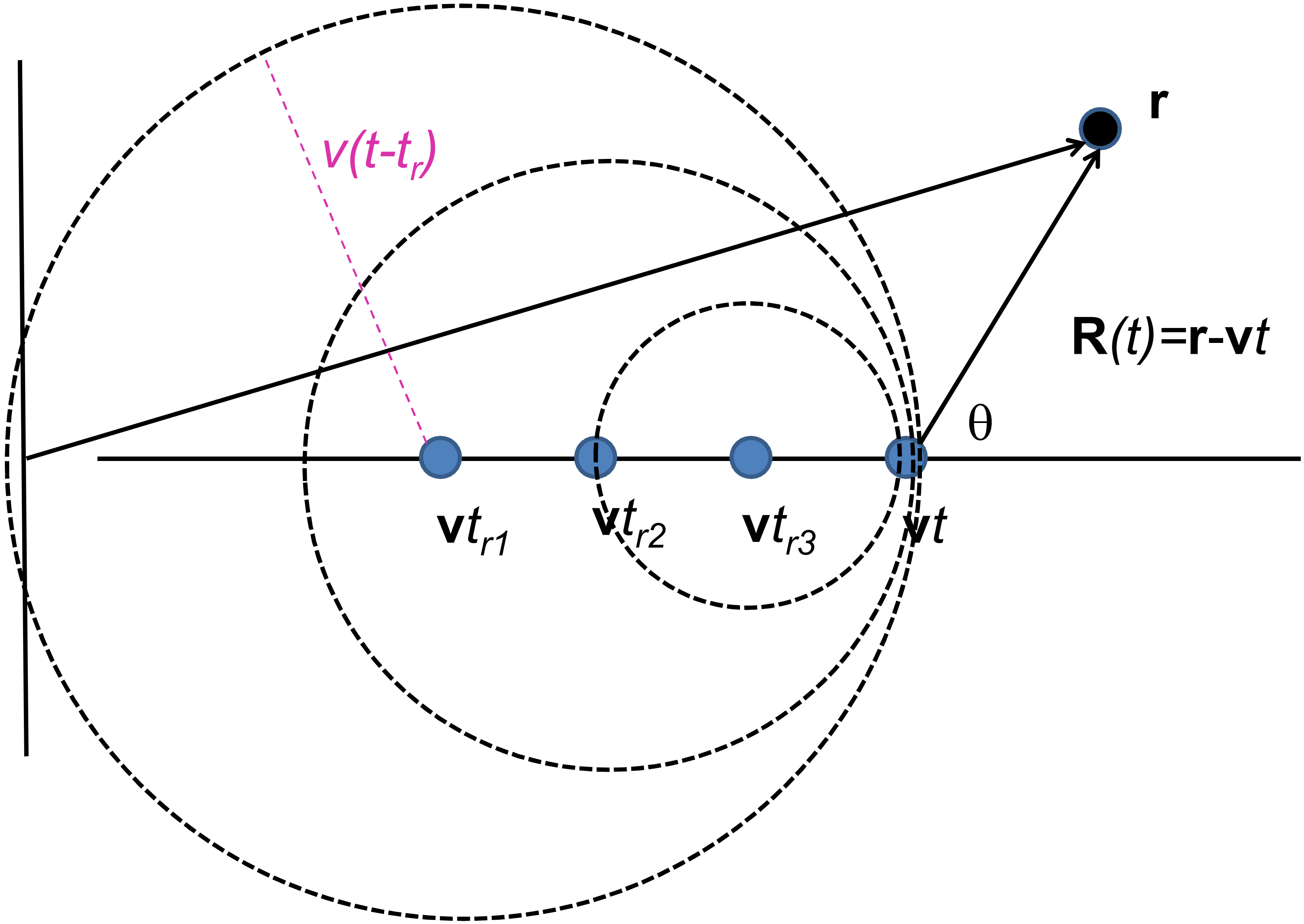
$$\Phi(\mathbf{r},t) = \frac{q}{\varepsilon} \frac{1}{R(t_r) - \boldsymbol{\beta}_n \cdot \mathbf{R}(t_r)}$$

$$\mathbf{A}(\mathbf{r},t) = q\mu \frac{\boldsymbol{\beta}_n}{R(t_r) - \boldsymbol{\beta}_n \cdot \mathbf{R}(t_r)}$$

$$\mathbf{R}(t_r) \equiv \mathbf{r} - \mathbf{R}_q(t_r)$$

$$\boldsymbol{\beta}_n(t_r) \equiv \frac{\dot{\mathbf{R}}_q(t_r)}{c_n} \qquad c_n \equiv \sqrt{\mu\varepsilon}\, c \equiv \frac{c}{n}$$

$$t_r = t - \frac{R(t_r)}{c_n}$$



r
v(t-t_r)
R(t)=r-vt
θ
vt_r1
vt_r2
vt_r3
vt

Some algebra

$$\mathbf{R}(t) = \mathbf{r} - \mathbf{v}t$$

$$\mathbf{R}(t_r) = \mathbf{r} - \mathbf{v}t_r = \mathbf{R}(t) + \mathbf{v}(t - t_r)$$

$$(t - t_r)c_n = R(t_r) = \left|\mathbf{R}(t) + \mathbf{v}(t - t_r)\right|$$

Quadratic equation for $(t - t_r)c_n$:

$$\left((t - t_r)c_n\right)^2 = R^2(t) + 2\mathbf{R}(t)\cdot\boldsymbol{\beta}_n(t - t_r)c_n + \beta_n{}^2\left((t - t_r)c_n\right)^2$$

$$(t - t_r)c_n = \frac{-\mathbf{R}(t)\cdot\boldsymbol{\beta}_n \pm \sqrt{\left(\mathbf{R}(t)\cdot\boldsymbol{\beta}_n\right)^2 - \left(\beta_n{}^2 - 1\right)R^2(t)}}{\beta_n{}^2 - 1}$$

$$\text{Some algebra -- continued}$$

$$\left(t-t_r\right)c_n = \frac{-\mathbf{R}(t)\cdot\boldsymbol{\beta}_n \pm \sqrt{\left(\mathbf{R}(t)\cdot\boldsymbol{\beta}_n\right)^2 - \left(\beta_n{}^2-1\right)R^2(t)}}{\beta_n{}^2-1}$$

$$\text{Denote:}\quad \mathbf{R}(t)\cdot\boldsymbol{\beta}_n \cong R(t)\beta_n\cos\theta(t)$$

$$\left(t-t_r\right)c_n = R(t)\frac{-\beta_n\cos\theta(t)\pm\sqrt{\beta_n{}^2\left(\cos^2\theta(t)-1\right)+1}}{\beta_n{}^2-1}$$

$$= R(t)\frac{-\beta_n\cos\theta(t)\pm\sqrt{1-\beta_n{}^2\sin^2\theta(t)}}{\beta_n{}^2-1}$$

Some algebra -- continued

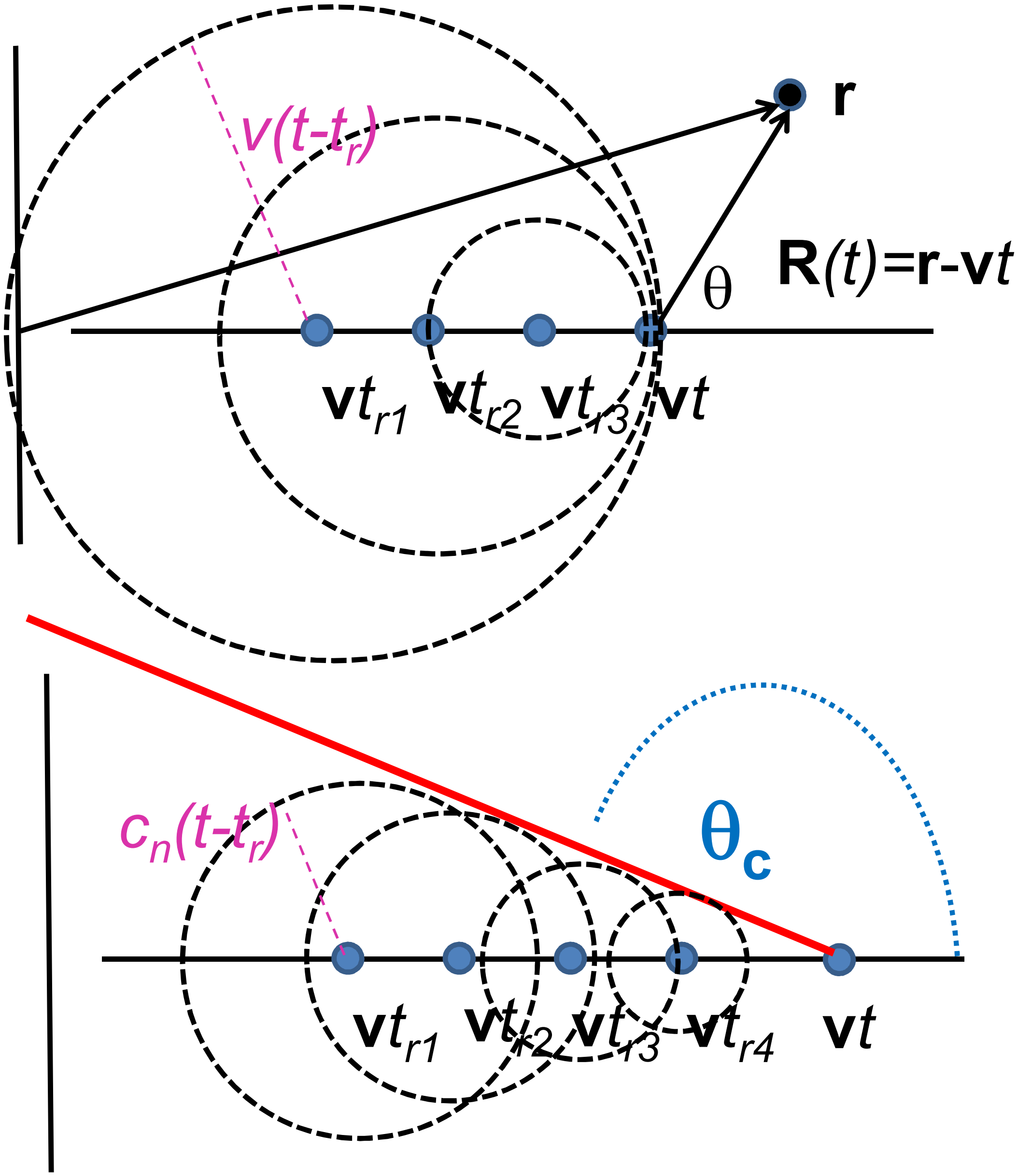
$$\left(t-t_r\right)c_n = R(t)\frac{-\beta_n\cos\theta(t)\pm\sqrt{1-\beta_n^{\,2}\sin^2\theta(t)}}{\beta_n^{\,2}-1}$$

Conditions for real solutions for $\theta(t)$ if $\beta_n \geq 1$:

$\cos\theta(t) \leq 0$ $\qquad\qquad$ $\left|\beta_n \sin\theta(t)\right| \leq 1$

$$\Rightarrow \frac{\pi}{2} \leq \theta(t) \leq \theta_C \qquad \text{where} \sin\theta_C \equiv \frac{1}{\beta_n} = \frac{c_n}{v}$$

$$\left(t-t_r\right)c_n = R(t)\frac{-\beta_n\cos\theta(t)\pm\sqrt{1-\beta_n^{\,2}\sin^2\theta(t)}}{\beta_n^{\,2}-1}$$


v(t-t_r)
r
R(t)=r-vt
θ
vt_r1
vt_r2
vt_r3
vt
c_n(t-t_r)
θ_c
vt_r1
vt_r2
vt_r3
vt_r4
vt

Liénard-Wiechert potential solutions for this case:

$$\Phi(\mathbf{r},t)=\frac{q}{\varepsilon}\frac{1}{R(t_r)-\boldsymbol{\beta}_n\cdot\mathbf{R}(t_r)}$$

$$\mathbf{A}(\mathbf{r},t)=q\mu\frac{\boldsymbol{\beta}_n}{R(t_r)-\boldsymbol{\beta}_n\cdot\mathbf{R}(t_r)}$$

$$\mathbf{R}(t_r)\equiv\mathbf{r}-\mathbf{R}_q(t_r)=\mathbf{R}(t)+\boldsymbol{\beta}_n c_n(t-t_r)$$

$$(t-t_r)c_n=R(t_r)=R(t)\frac{-\beta_n\cos\theta(t)\pm\sqrt{1-\beta_n^{\ 2}\sin^2\theta(t)}}{\beta_n^{\ 2}-1}$$

Liénard-Wiechert potential solutions -- continued:

$$\Phi(\mathbf{r},t) = \frac{2q}{\varepsilon} \frac{1}{R(t)\sqrt{1-\beta_n{}^2 \sin^2\theta(t)}} \Theta(\cos\theta_C - \cos\theta(t))$$

$$\mathbf{A}(\mathbf{r},t) = 2q\mu \frac{\boldsymbol{\beta}_n}{R(t)\sqrt{1-\beta_n{}^2 \sin^2\theta(t)}} \Theta(\cos\theta_C - \cos\theta(t))$$

Electric and magnetic fields:

$$\mathbf{E}(\mathbf{r},t) = -\nabla\Phi(\mathbf{r},t) - \frac{1}{c}\frac{\partial \mathbf{A}(\mathbf{r},t)}{\partial t}$$

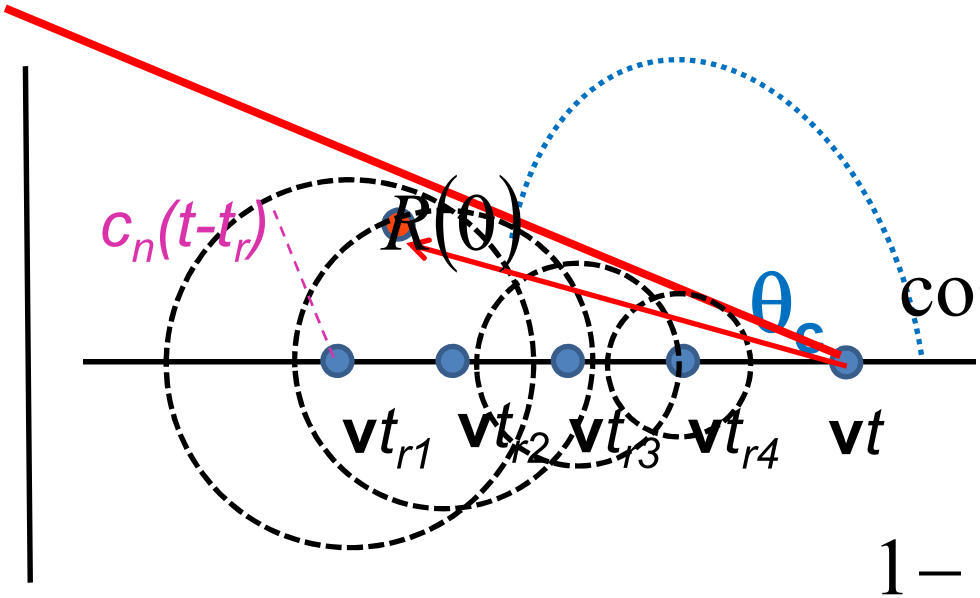
$$\mathbf{B}(\mathbf{r},t) = \nabla \times \mathbf{A}(\mathbf{r},t)$$

Liénard-Wiechert potential solutions -- continued:

$$\mathbf{E}(\mathbf{r},t) = -\frac{2q}{\varepsilon}\frac{\hat{\mathbf{R}}(t)\left(\beta_n{}^2 - 1\right)}{\left(R(t)\right)^2\left(1-\beta_n{}^2\sin^2\theta(t)\right)^{3/2}}\Theta\left(\cos\theta_C - \cos\theta(t)\right)$$

$$+\frac{2q}{\varepsilon}\frac{\hat{\mathbf{R}}(t)\left(\beta_n{}^2 - 1\right)^{1/2}/\beta_n}{\left(R(t)\right)^2\left(1-\beta_n{}^2\sin^2\theta(t)\right)^{1/2}}\delta\left(\cos\theta_C - \cos\theta(t)\right)$$

$$\mathbf{B}(\mathbf{r},t) = -\beta_n \sin\theta(t)\left(\hat{\boldsymbol{\theta}}(t)\times\mathbf{E}(\mathbf{r},t)\right)$$



$$\cos\theta_C - \cos\theta(t) \approx \frac{c_n t}{\beta_n R(0)}$$

$$1-\beta_n \sin^2\theta(t) \approx \frac{2c_n t\sqrt{\beta_n^{\;2}-1}}{R(0)}$$

When the dust clears....

$$\frac{d^2 I}{d\omega d\ell} \propto \left(1-\frac{c_n^{\;2}}{v^2}\right)\omega$$