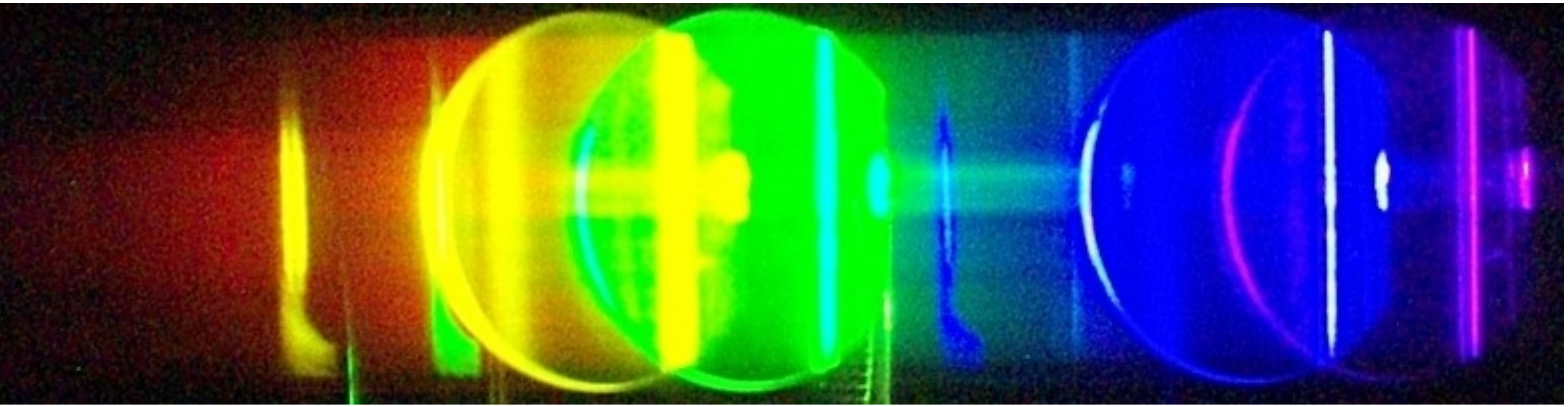

PH495 / ECE493 Optics

Dr. LeClair, Dr. Kung

PH495/ECE493 OPTICS

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  offices: 2012 Bevill, 110 Gallalee; 857-891-4267 (cell)
- LeClair office hours: (email/txt ahead ideally)

  M 1-2 in Gallalee 110

  Tu, Th 12:15-1:15 in Gallalee 110

  W ~1-3 in Bevill 2012

  other times by appointment

OFFICIAL THINGS, CONT.

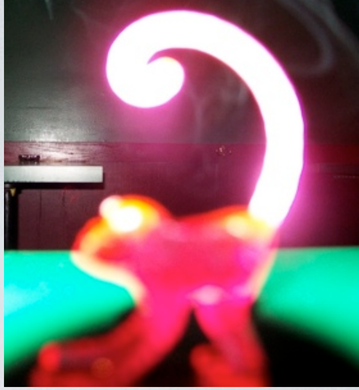
- Lecture:

  311 Houser (obviously)

  TuTh 9:30-10:45

- we'll need most of this time
- will go over problems, but only so many
- a big part of learning is solving on your own ...
- some notes provided (scanned or otherwise)
- no attendance policy,

TOPICS

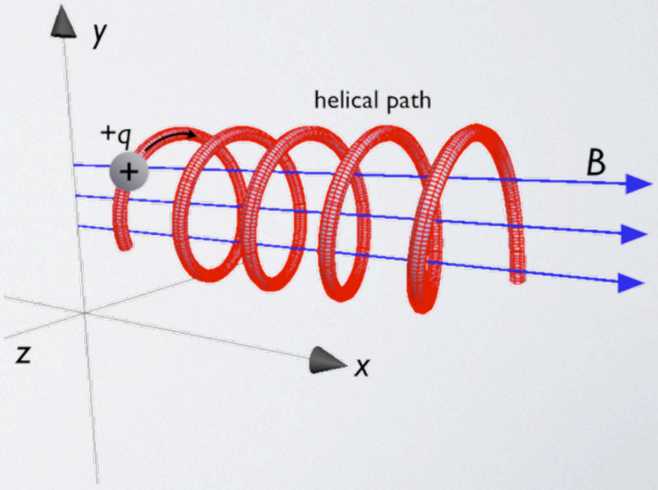


1. Electromagnetic theory, photons, light (3.0 hrs)
2. Propagation of light (6.0 hrs)
3. Geometrical optics (7.5 hrs)
4. Polarization (4.5 hrs)
5. Interference (4.5 hrs)
6. Diffraction (4.5 hrs)
7. Modern optics: lasers, fiber optics, holography (3.0 hrs)
8. Midterm Examinations (2) (3.0 hrs)

LAB EXPERIMENTS

take the place of a lecture, 2 groups

1. Introduction to optics and components (1.5 hrs)
2. Refractive index (1.5 hrs)
3. Interferometry (1.5 hrs)
4. Diffraction (1.5 hrs)
5. Spectral composition of light (1.5 hrs)
6. Optical devices (1.5 hrs)



SCHEDULE ALREADY DIVERGED

Date	Primary topic	Secondary topic	Reading	Instructor
13 Jan	Review: wave motion	superposition of waves	2.1-2.9; 7.1-2	PL
18	Electromagnetic theory	Photons, light	3.1-3	PL
20	Radiation	Scattering	3.4-6	PL
25	Propagation of light 1	Reflection & refraction	4.2-5	PL
27	Propagation of light 2		4.6-8	PL
1 Feb	Propagation of light 3		4.9-11	PL
3	Geometric optics 1		5.1-4	PK
8	Geometric optics 2 (A)	Lab 1: optics components (B)	5.4-7	PK / PL
10	Geometric optics 2 (B)	Lab 1: optics components (A)	5.4-7	PK / PL
15	Geometric optics 3 (A)	Lab 2: refractive index (B)	6.1-4	PK / PL
17	Geometric optics 3 (B)	Lab 2: refractive index (A)	6.1-4	PK / PL
22	Polarization 1		8.1-6	PK
24	Polarization 2		8.7-12	PK
1 Mar	EXAM 1			
3	Interference 1		9.1-3	PL
8	Interference 2		9.4-6	PL
10	Interference 3 (A)	Lab 3: interferometry (B)	9.7-8	PL/PK
22	Interference 3 (B)	Lab 3: interferometry (A)	9.7-8	PL/PK
24	Diffraction 1		10.1-2	PL
29	Diffraction 2 (A)	Lab 4: diffraction (B)	10.3-5	PL/PK
31	Diffraction 2 (B)	Lab 4: diffraction (A)	10.3-5	PL/PK
5 April	EXAM 2			
7	Lasers 1 (A)	Lab 5: optical devices (B)	13	PK/PL
12	Lasers 1 (B)	Lab 5: optical devices (A)	13	PK/PL
14	Lasers 2 (A)	Lab 6: spectral composition of light (B)	13	PK/PL
19	Lasers 2 (B)	Lab 6: spectral composition of light (A)	13	PK/PL
21	Fiber optics		13	PK
26	Holography		13	PK
28	TBD			
3 May	8-10:30am FINAL			

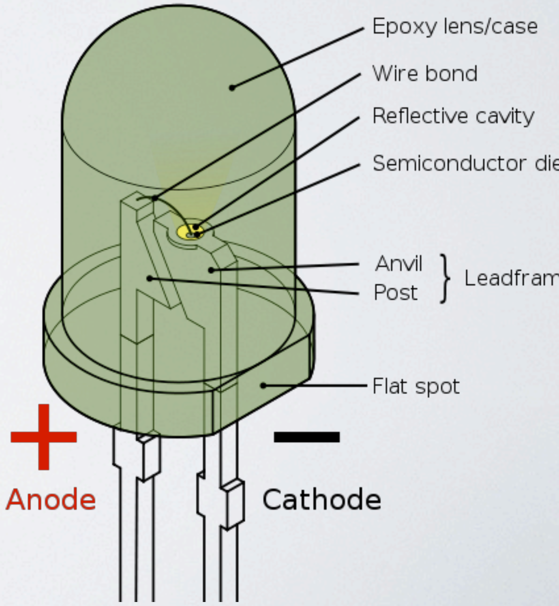
GRADING

- 2 exams (during class period)
- homework ~weekly, drop lowest

Homework	15%
Labs	15%
Exam I	20%
Exam II	20%
Final	30%

HOMEWORK

- for my homework: email or hard copy OK
- collaboration is OK, but turn in your own
- have to show work for credit
- problem sets posted on course web page



INTERTUBES

- web page ... RSS feed, updated often

    can add RSS feed to facebook if that's how you roll

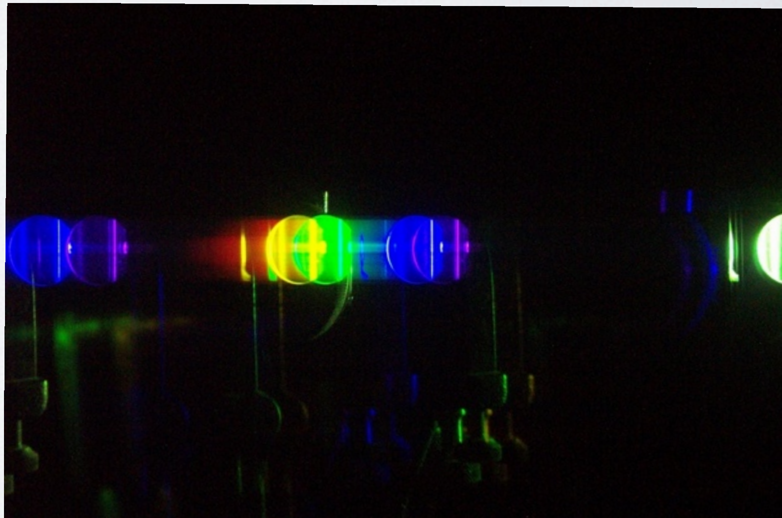
- twitter @pleclair #ua-optics reproduces posts; tweets to blog sidebar
- google calendar (you can subscribe)

    click on 'event details' for reading

- check blog and calendar frequently (or, learn to love RSS or twitter)

STUFF YOU NEED

- Hecht, 'Optics'
- calculator with basic trig/log functions minimally
- writing implements
- probably, Wolfram Alpha



USEFUL THINGS

Purcell, Edward M. *Electricity and Magnetism.* In Berkeley Physics Course. 2nd ed. Vol. 2. New York, NY: McGraw-Hill, 1984. ISBN: 9780070049086.

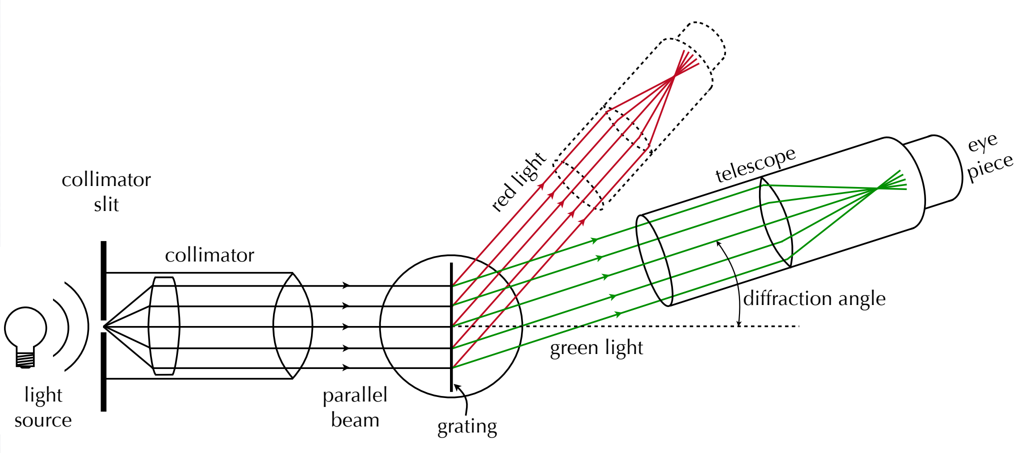
Feynman, Richard P., Robert B. Leighton, and Matthew Sands. *The Feynman Lectures on Physics.* 2nd ed. Vol. 2. Reading, MA: Addison-Wesley, 2005. ISBN: 9780805390452.

(online notes posted for some lectures)
(slides always posted following lecture)

SHOWING UP

- we hope you will find some utility in the class
- homework/exams may rely on stuff I say in class
- missing an exam is seriously bad.

  acceptable reason ... makeup or weight final



OTHER

- Parking tickets start at $25
- Calculus fluency assumed (through Cal II)
- Physics fluency assumed (through PH106)
- Glance through Ch. 2 to make sure it is review

  your homework for next week is on this
- Read Ch. 3 for next lecture; much of it should be review

Quick advertisement:

Phy-EE double major

- Electrical and Computer Engineering majors need ~ 4 additional hours to complete a second major in Physics.
- This combination of fundamental and applied physics can be highly advantageous when the graduate enters the job market.

QUICK POLL:

- Have you taken MA 227?
- MA 238?
- PH 253?
- PH 331?
- ECE 340?

TODAY & NEXT TIME:

"REVIEW" OF ELECTRODYNAMICS

(BUT FIRST SOME MATH)

DIV, **GRAD**, **CURL** AND ALL THAT

$$\mathbf{grad}\ F = \nabla F$$

$$\nabla F = \frac{\partial F}{\partial x}\,\hat{x} + etc.$$

vector pointing in direction of greatest rate of increase

e.g., scalar field describing temperature in room

gradient points in direction where temp rises most quickly

ever play that game of 'warm' and 'cold' ?

$$\mathbf{div}\vec{F} = \nabla \cdot \vec{F} \qquad \mathbf{div}\vec{F} = \frac{\partial F_x}{\partial x} + etc.$$

‘source function’
how much stuff comes from somewhere

magnitude of vector field’s
source or sink at a point (a scalar)

if the field is the velocity of air expanding as heated,
divergence is *positive*, air is expanding -- source
for cooling/contracting air, it is negative -- sink

Gauss’ law - enclosed sources + sinks in a volume
says “charges = source of E”
crucial for any sort of plumbing work.

$$\textbf{curl}\ \vec{F} = \nabla \times \vec{F}$$

vector field's rate of rotation

direction of axis of rotation (position)

magnitude of rotation (position)

'circulation density'

zero curl = 'irrotational'

paddlewheel measures curl of water flow

$$\textbf{curl F} = \det \begin{bmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ F_x & F_y & F_z \end{bmatrix}$$

INTERESTING IDENTITIES WE MAY USE

$$\nabla \cdot (\nabla f) = \nabla^2 f = \frac{\partial^2 f}{\partial x^2} + etc.$$

$$\nabla \cdot (\nabla \times \vec{A}) = 0$$

$$\nabla \cdot (\nabla \times f) = 0$$

$$\nabla \times (\nabla f) = 0$$

$$\nabla \times (\nabla \times \vec{A}) = \nabla(\nabla \cdot \vec{A}) - \nabla^2 \vec{A}$$

Maxwell's equations in integral form

Gauss
$$\oint_S \vec{\mathbf{D}} \cdot d\vec{\mathbf{A}} = q_{\text{encl}} = \int_V \rho_{\text{encl}}\, dV$$

Magnetic Gauss
$$\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$

Faraday
$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = -\frac{\partial}{\partial t}\int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

Ampere
$$\oint_C \vec{\mathbf{H}} \cdot d\vec{\mathbf{l}} = \int_S \vec{\mathbf{j}} \cdot d\vec{\mathbf{A}} + \frac{\partial}{\partial t}\int_S \vec{\mathbf{D}} \cdot d\vec{\mathbf{A}}$$

In the absence of polarization density or magnetization

Gauss
$$\oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q}{\epsilon_0 \epsilon_r} = \frac{1}{\epsilon_0 \epsilon_r}\int_V \rho\, dV$$

Magnetic Gauss
$$\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$

Faraday
$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = -\frac{\partial}{\partial t}\int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

Ampere
$$\epsilon_0 c^2 \oint_C \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \int_S \vec{\mathbf{j}} \cdot d\vec{\mathbf{A}} + \epsilon_r \frac{\partial}{\partial t}\int_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}}$$

Maxwell's Equations in SI Units

Maxwell's equations in differential form

Gauss $\vec{\nabla}\cdot\vec{\mathbf{D}} = \epsilon_0\vec{\nabla}\cdot\vec{\mathbf{E}} + \vec{\nabla}\cdot\vec{\mathbf{P}} = \rho_{\text{free}}$ charge creates E

Magnetic Gauss $\vec{\nabla}\cdot\vec{\mathbf{B}} = 0$ no magnetic monopoles

Faraday $\vec{\nabla}\times\vec{\mathbf{E}} = -\frac{\partial\vec{\mathbf{B}}}{\partial t}$ time-varying flux gives potential

Ampere $\vec{\nabla}\times\vec{\mathbf{H}} = c^2\vec{\nabla}\times\vec{\mathbf{B}} - c^2\vec{\nabla}\times\vec{\mathbf{M}} = \vec{\mathbf{j}} + \frac{\partial\vec{\mathbf{D}}}{\partial t}$ moving charge causes B/H

Displacement field, Magnetic fields, and charge density

$$\vec{\mathbf{D}} = \epsilon_0\vec{\mathbf{E}} + \vec{\mathbf{P}} \approx \epsilon_r\epsilon_0\vec{\mathbf{E}}$$

displacement field = polarization + E

$$\vec{\mathbf{H}} = \frac{1}{\mu_0}\left(\vec{\mathbf{B}} - \vec{\mathbf{M}}\right) = \epsilon_0 c^2\left(\vec{\mathbf{B}} - \vec{\mathbf{M}}\right)$$

magnetic field strength = magnetic field - magnetization

$$\rho_{\text{total}} = \rho_{\text{free}} + \rho_{\text{pol}}$$

total charge = free + polarization

In the absence of polarization density or magnetization

Gauss	$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_r \epsilon_0}$
Magnetic Gauss	$\vec{\nabla} \cdot \vec{B} = 0$
Faraday	$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
Ampere	$\epsilon_0 c^2 \vec{\nabla} \times \vec{B} = \vec{j} + \epsilon_r \frac{\partial \vec{E}}{\partial t}$

Note that $c^2 = \frac{1}{\mu_0 \epsilon_0}$. We do not need all three.

Maxwell's Equations in SI Units: static case

In the absence of polarization density or magnetization

$$\vec{\nabla} \cdot \vec{\mathbf{E}} = \frac{\rho}{\epsilon_r \epsilon_0}$$

$$\vec{\nabla} \cdot \vec{\mathbf{B}} = 0$$

$$\vec{\nabla} \times \vec{\mathbf{E}} = -\cancel{\frac{\partial \vec{\mathbf{B}}}{\partial t}}$$

$$\epsilon_0 c^2 \vec{\nabla} \times \vec{\mathbf{B}} = \cancel{\vec{\mathbf{j}}} + \epsilon_r \cancel{\frac{\partial \vec{\mathbf{E}}}{\partial t}}$$

$$\Downarrow$$

In the absence of polarization density or magnetization

$$\vec{\nabla} \cdot \vec{\mathbf{E}} = \frac{\rho}{\epsilon_r \epsilon_0}$$

$$\vec{\nabla} \cdot \vec{\mathbf{B}} = 0$$

$$\vec{\nabla} \times \vec{\mathbf{E}} = 0$$

$$\epsilon_0 c^2 \vec{\nabla} \times \vec{\mathbf{B}} = 0$$

#2

In the absence of polarization density or magnetization

Gauss

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_r \epsilon_0}$$

Faraday

$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

Magnetic Gauss

$$\epsilon_0 c^2 \vec{\nabla} \times \vec{B} = \vec{j} + \epsilon_r \frac{\partial \vec{E}}{\partial t}$$

Ampere

Solutions: vector and scalar potentials

$$\vec{E} = -\vec{\nabla}\varphi - \frac{\partial \vec{A}}{\partial t}$$

scalar potential

$$\vec{B} = \vec{\nabla} \times \vec{A}$$

vector potential

$$\varphi(1,t) = \int \frac{\rho(2, t - r_{12}/c)}{4\pi\epsilon_0 r_{12}} dV_2$$

retarded response

$$\vec{A}(1,t) = \int \frac{\vec{j}(2, t - r_{12}/c)}{4\pi\epsilon_0 c^2 r_{12}} dV_2$$

usually take Coulomb gauge, $\vec{\nabla} \cdot \vec{\mathbf{A}} = 0$:

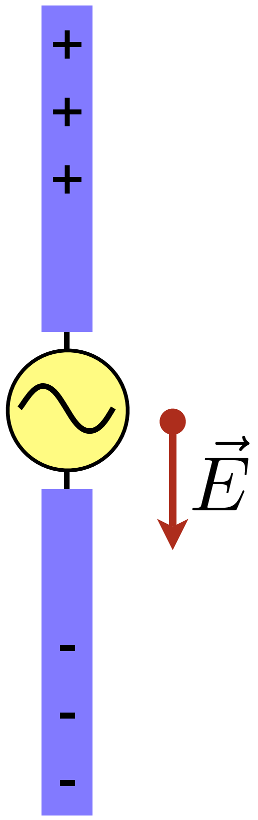
Poisson

$$-\nabla^2 \varphi = \frac{\rho}{\epsilon_0}$$

$$-\epsilon_0 c^2 \nabla^2 \vec{\mathbf{A}} = j$$

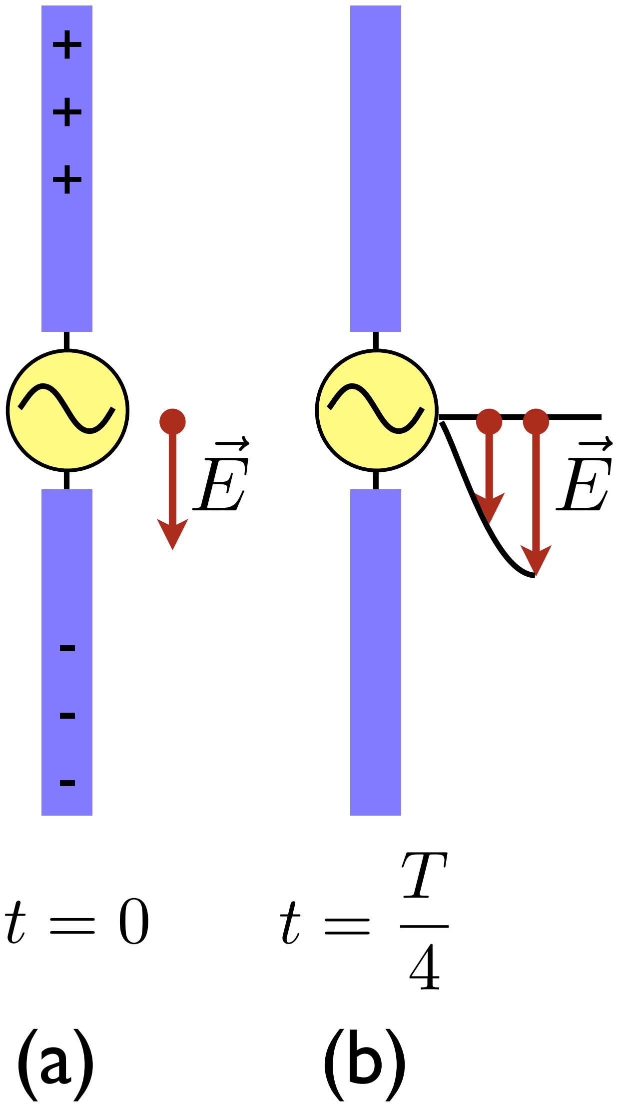
div + curl specifies E (almost) uniquely
curl E follows from central nature of force + f(r) only

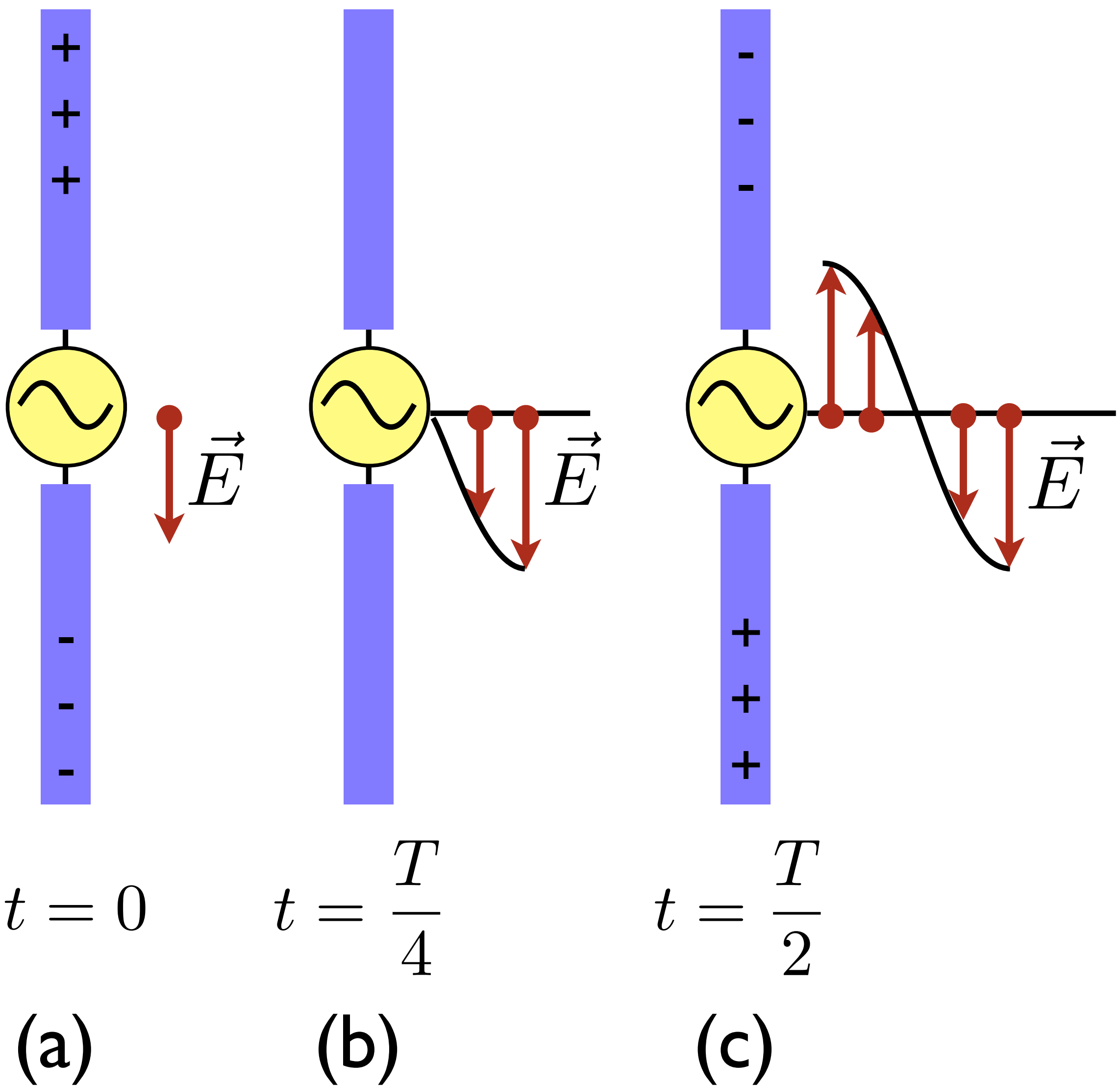
div + curl gives E = grad (scalar)
and Poisson

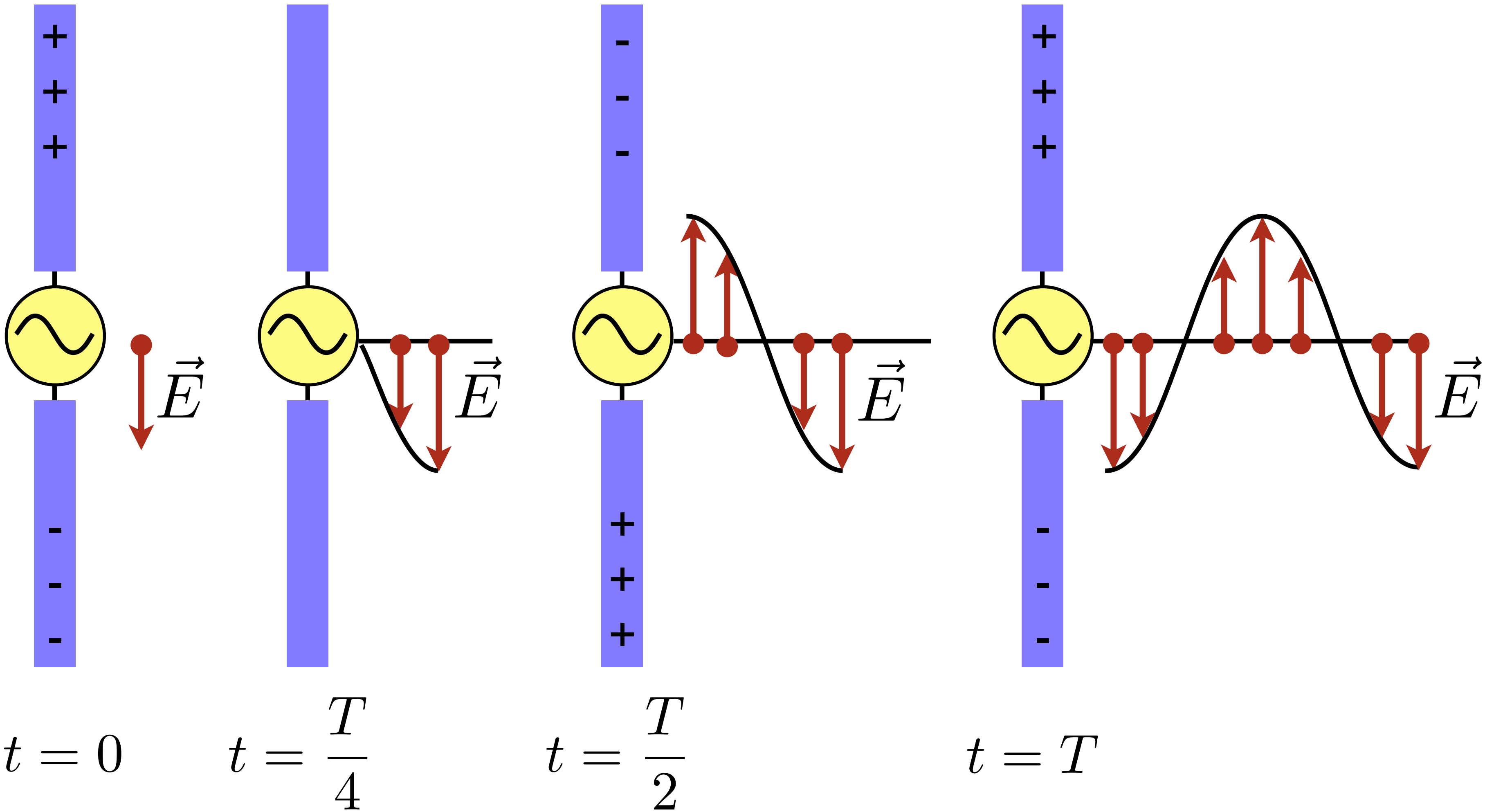


$t = 0$

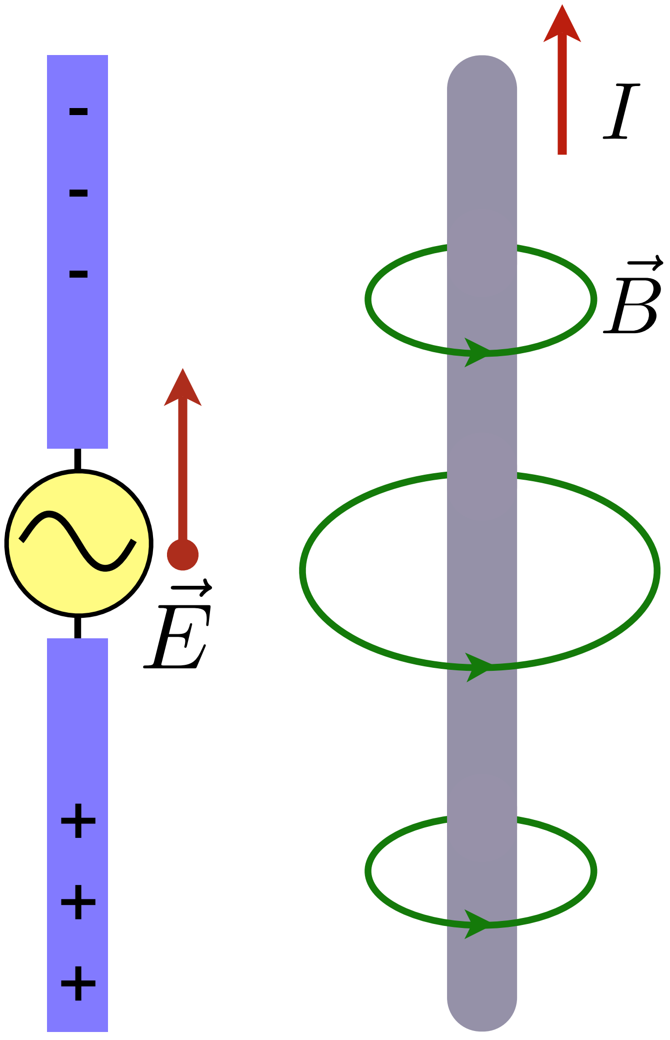
(a)


+
+
+
$\vec{E}$
-
-
-
$\vec{E}$
$t = 0$
$t = \frac{T}{4}$
(a)
(b)


+ + +
- - -
$\vec{E}$
$t = 0$
(a)
$t = \frac{T}{4}$
(b)
$t = \frac{T}{2}$
(c)

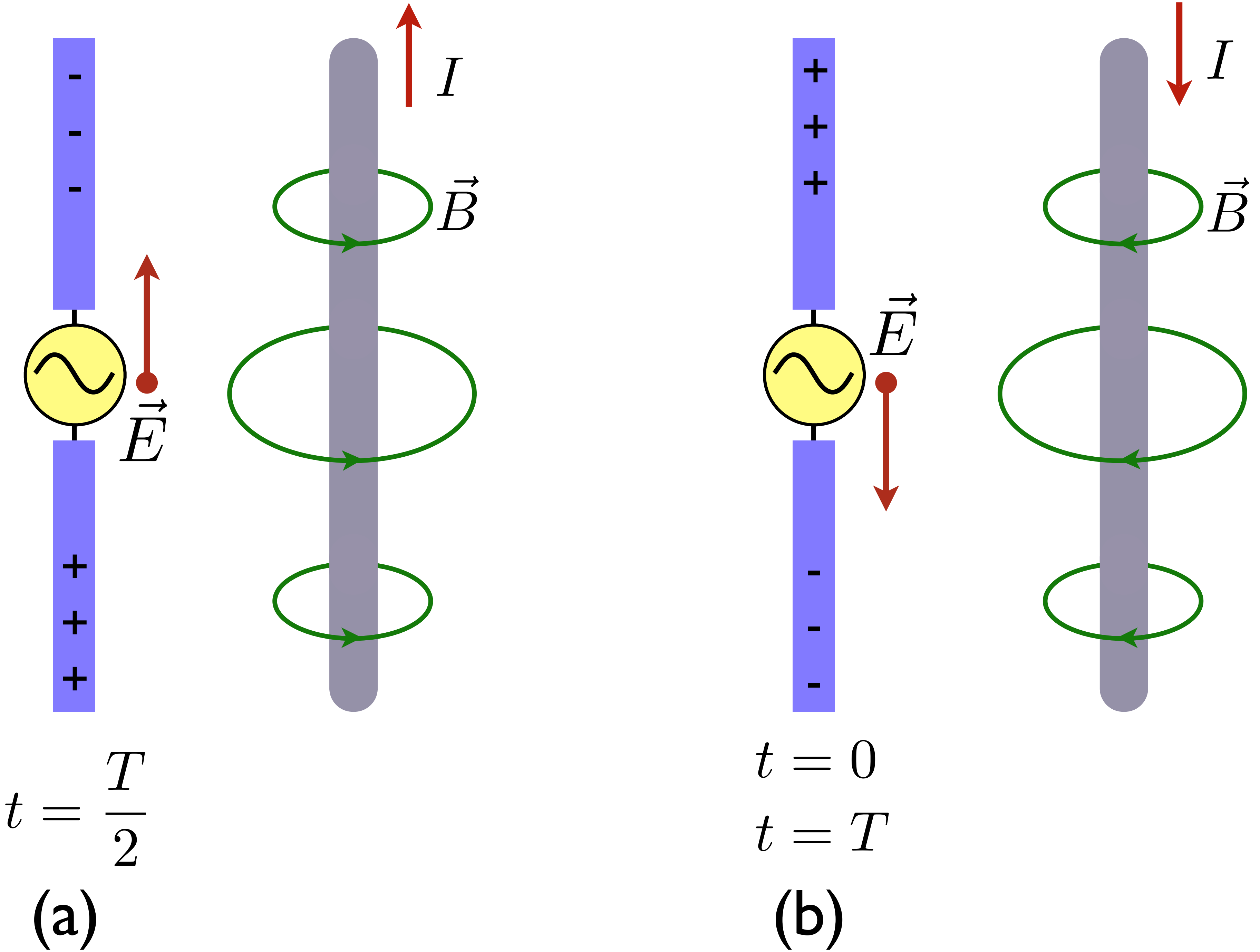


(a) (b) (c) (d)

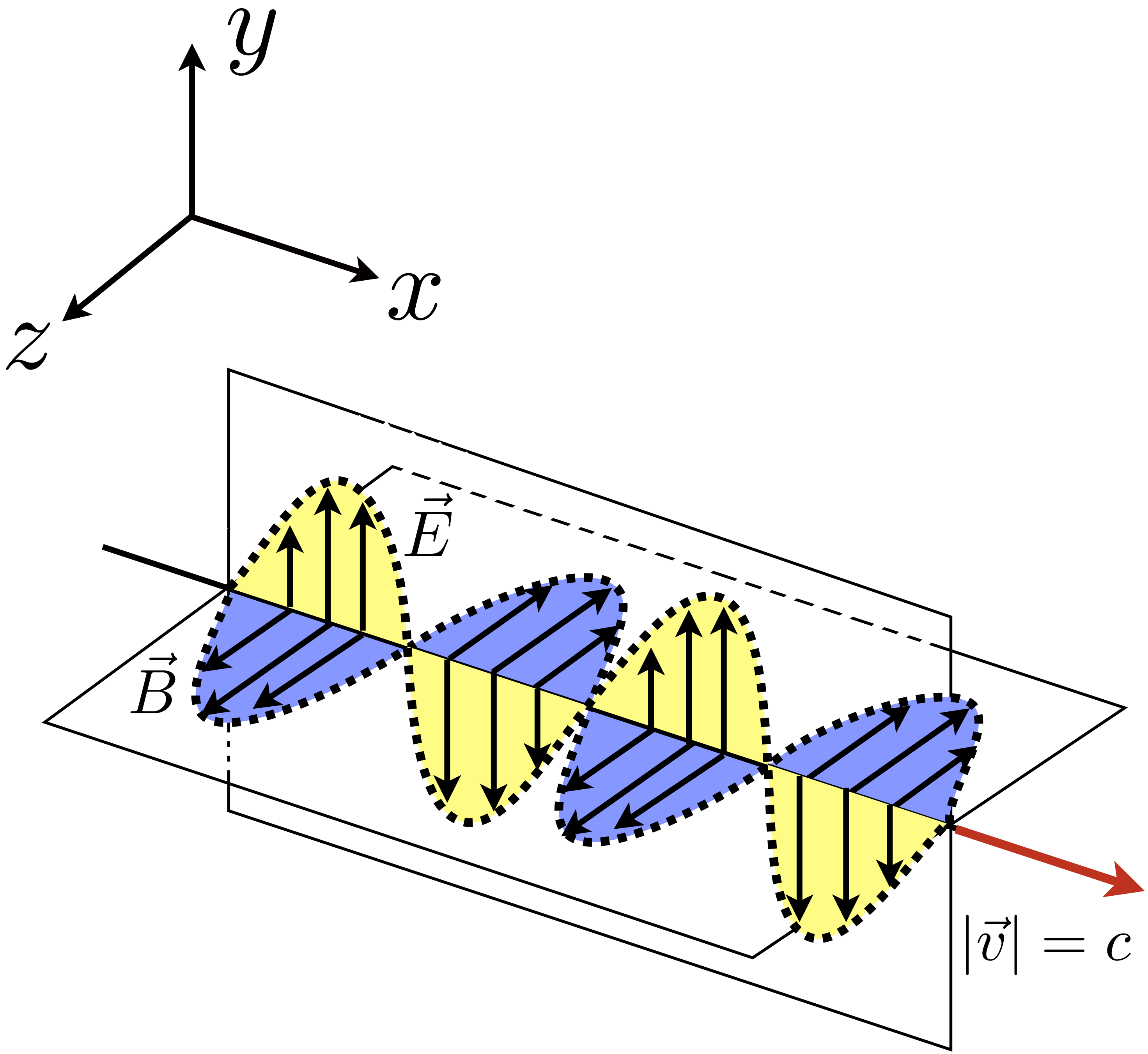


$$t = \frac{T}{2}$$

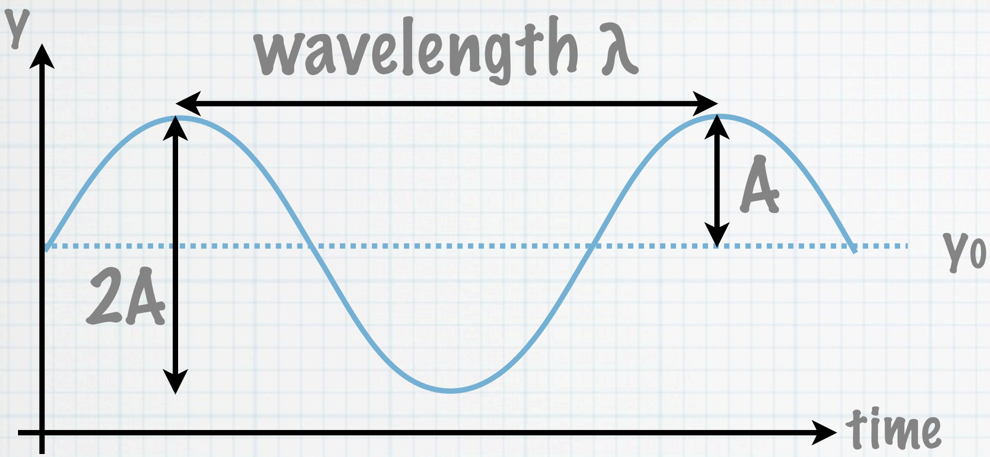
(a)



-
-
-
+
+
+
I
$\vec{B}$
$\vec{E}$
$t = \frac{T}{2}$
(a)
+
+
+
-
-
-
I
$\vec{B}$
$\vec{E}$
$t = 0$
$t = T$
(b)



y
x
z
$\vec{E}$
$\vec{B}$
$|\vec{v}| = c$



λ characterizes SPATIAL variation

f characterizes TIME variation

T = Period = how long per cycle

$T = 1/f$ or $f = 1/T$

frequency - wavelength - velocity:

$\lambda f = v$ = velocity of wave propagation

or $vT = \lambda$ .... travel one wavelength per period

simplest wave:

$$f(x,t) = A\sin\left(2\pi f t - \frac{2\pi}{\lambda}x\right)$$

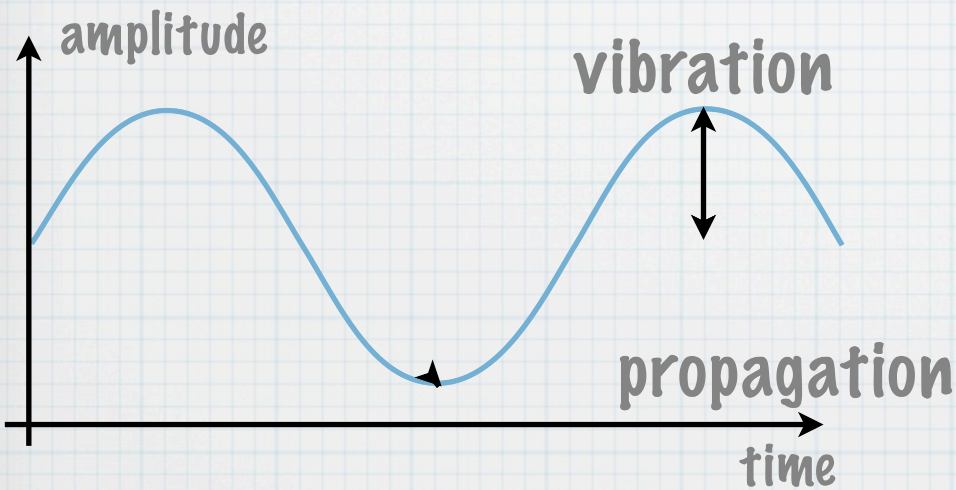
Characteristics of waves

they have Crests & Troughs

- intensity varies periodically. "vibration"

Longitudinal

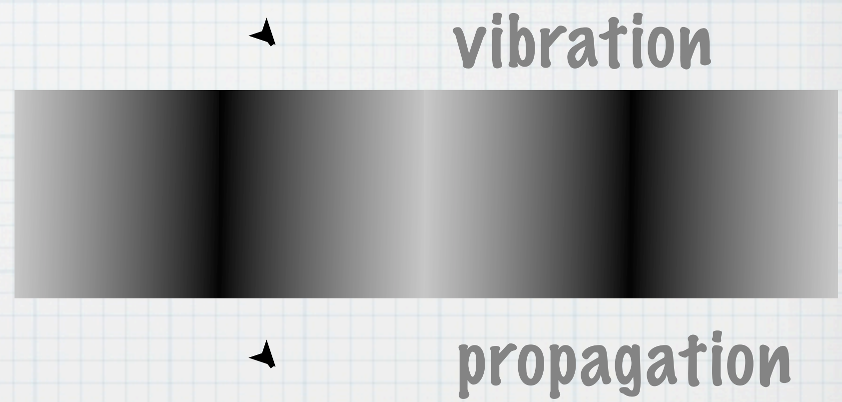
vibrations are
PERPENDICULAR
to propagation



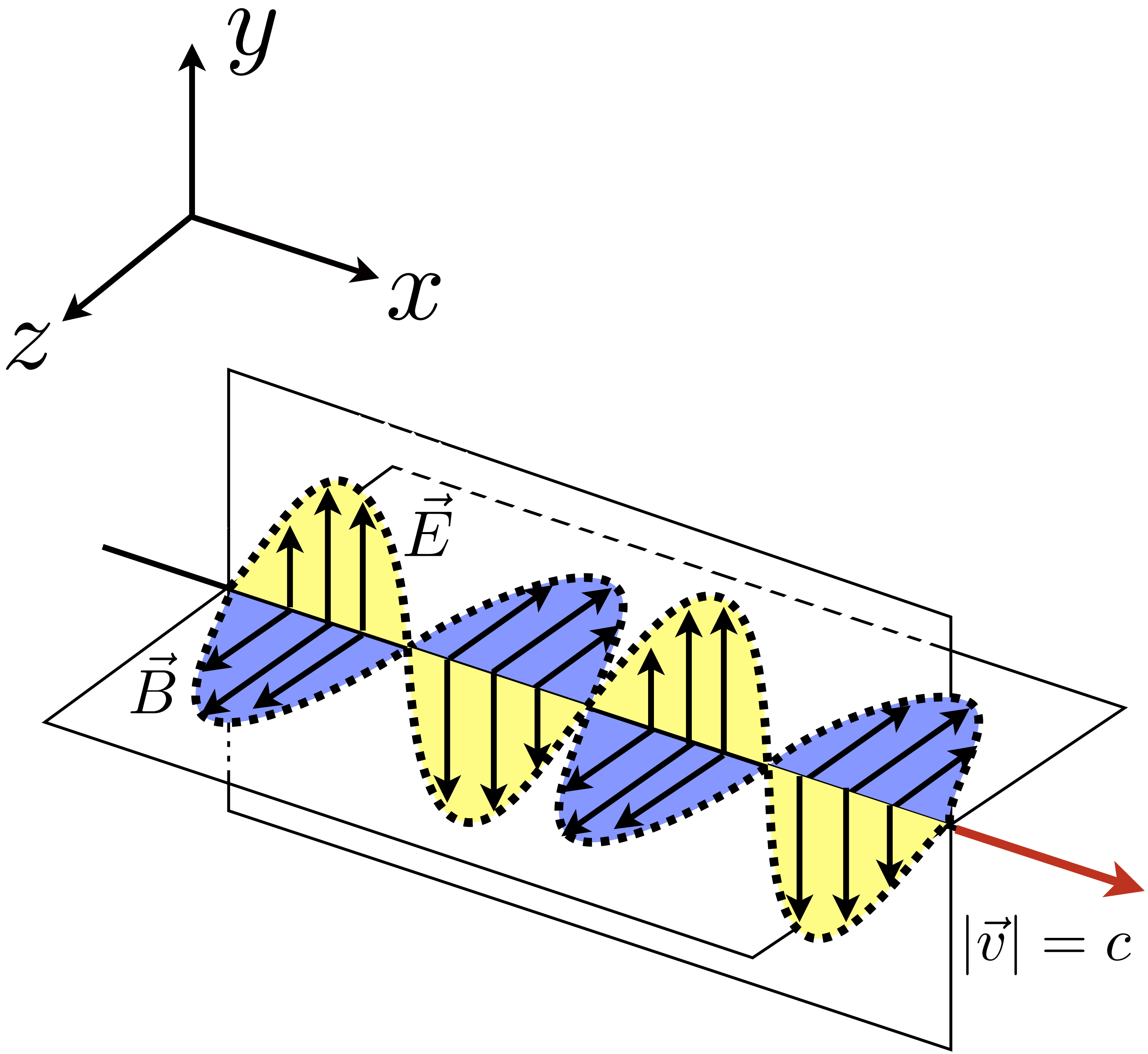
string, EM waves

Transverse

vibrations are
PARALLEL
to propagation

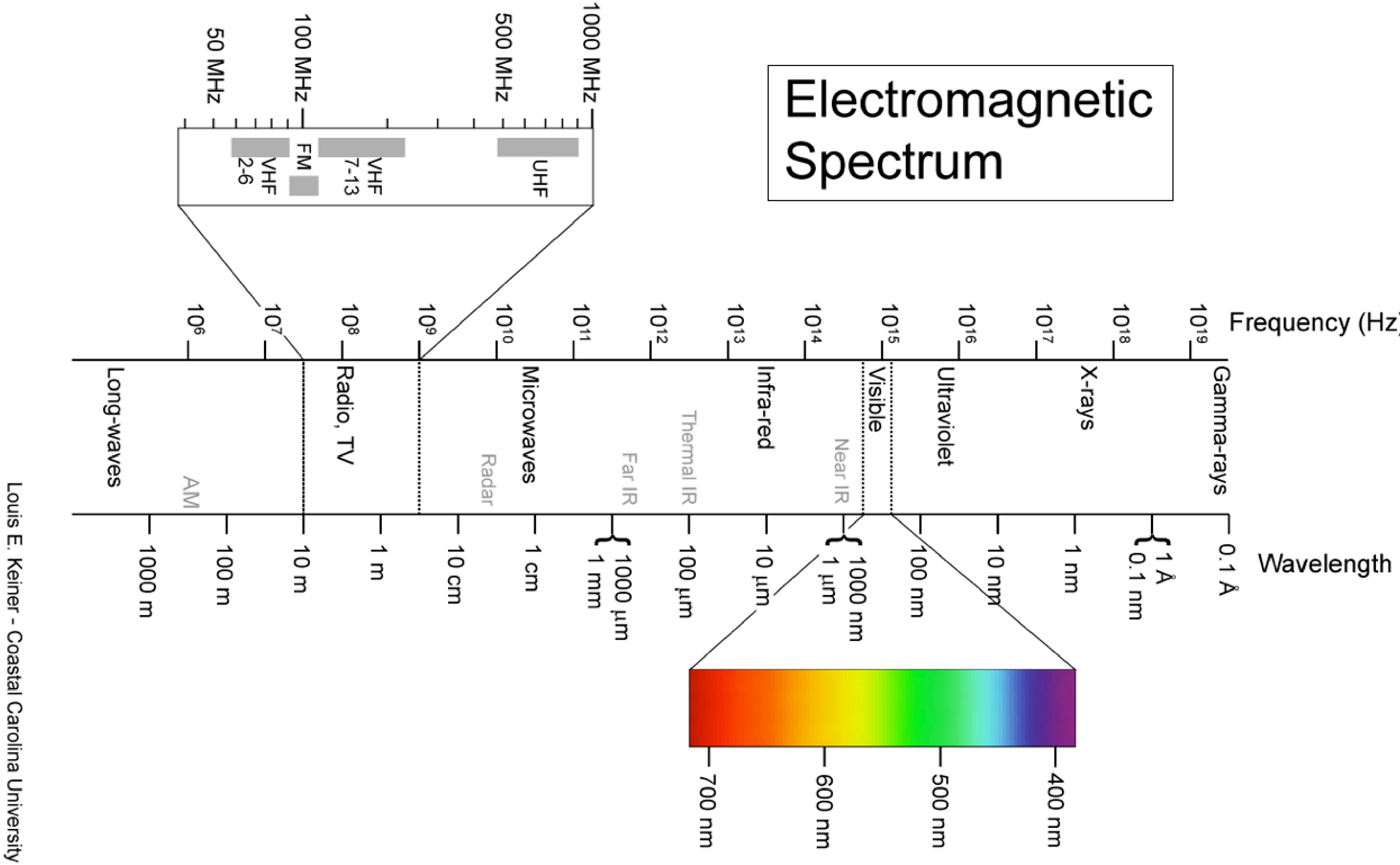


sound



y
x
z
$\vec{E}$
$\vec{B}$
$|\vec{v}| = c$

Electromagnetic Spectrum



What do I have against μ_0?

It is unnecessary

μ_0 is *defined* as a constant

it is just a combination of ε_0 and c

$$c^2 = \frac{1}{\mu_0 \epsilon_0}$$

It hides the relativistic connection between E and B

there is only 1 field. E and B are connected

by a Lorenz transformation

The strength of E per unit charge is scaled by ε_0

The strength of B is a factor c^2 *smaller via Lorenz*

we could also start with B and get rid of ε_0, *just to be fair*

but we do not need two constants AND c

Gauss' law + symmetry gives Coulomb's law

$$\text{flux} = \oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{1}{\epsilon_0}\int_V \rho(r)\, dV = \frac{q_{\text{encl}}}{\epsilon_0}$$

If the charge distribution is radially symmetric, field lines *spread out radially, equally in all directions*:

$$\vec{\mathbf{E}} = E(r)\,\hat{\mathbf{r}}$$

By symmetry, the field strength must then go as $\frac{1}{r^2}$.

$\Longrightarrow$ field is constant at a given radius $\Longrightarrow$ Gaussian surface = sphere

$$\Phi = \oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \varphi = \vec{\mathbf{E}} \oint_S \cdot\, d\vec{\mathbf{A}} = \vec{\mathbf{E}} \cdot 4\pi r^2\,\hat{\mathbf{r}} = \frac{q_{\text{encl}}}{\epsilon_0}$$

Symmetry + Gauss = Coulomb:

$$\vec{\mathbf{E}} = \frac{q_{\text{encl}}}{4\pi\epsilon_0 r^2}\,\hat{\mathbf{r}}$$

hand waving to save time

GEOMETRIC INTERPRETATION

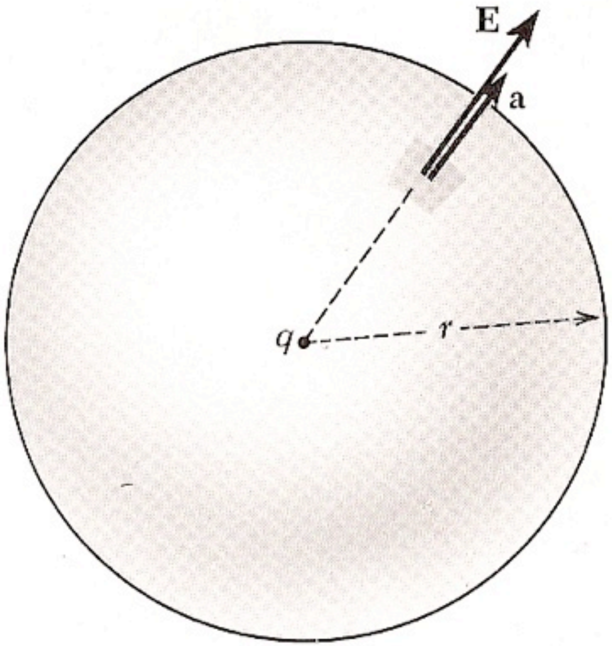


FIGURE 1.15
In the field **E** of a point charge q, what is the outward flux over a sphere surrounding q?

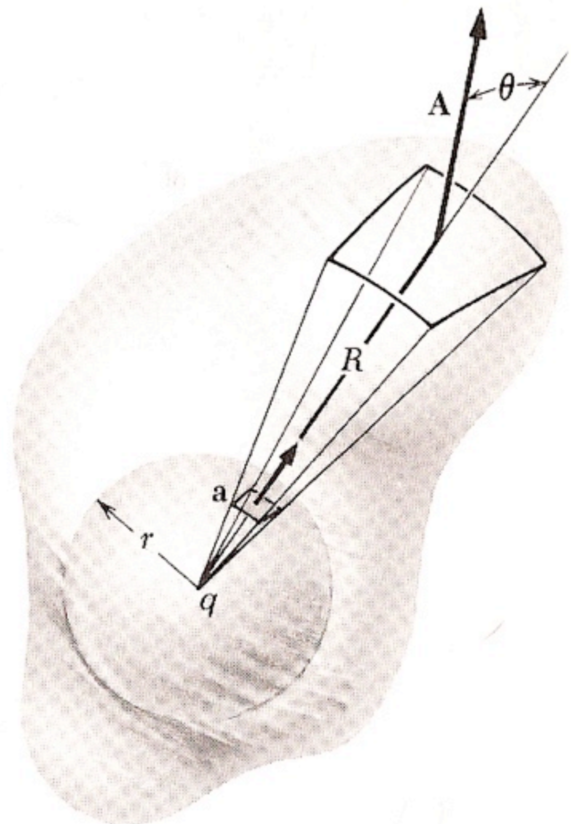


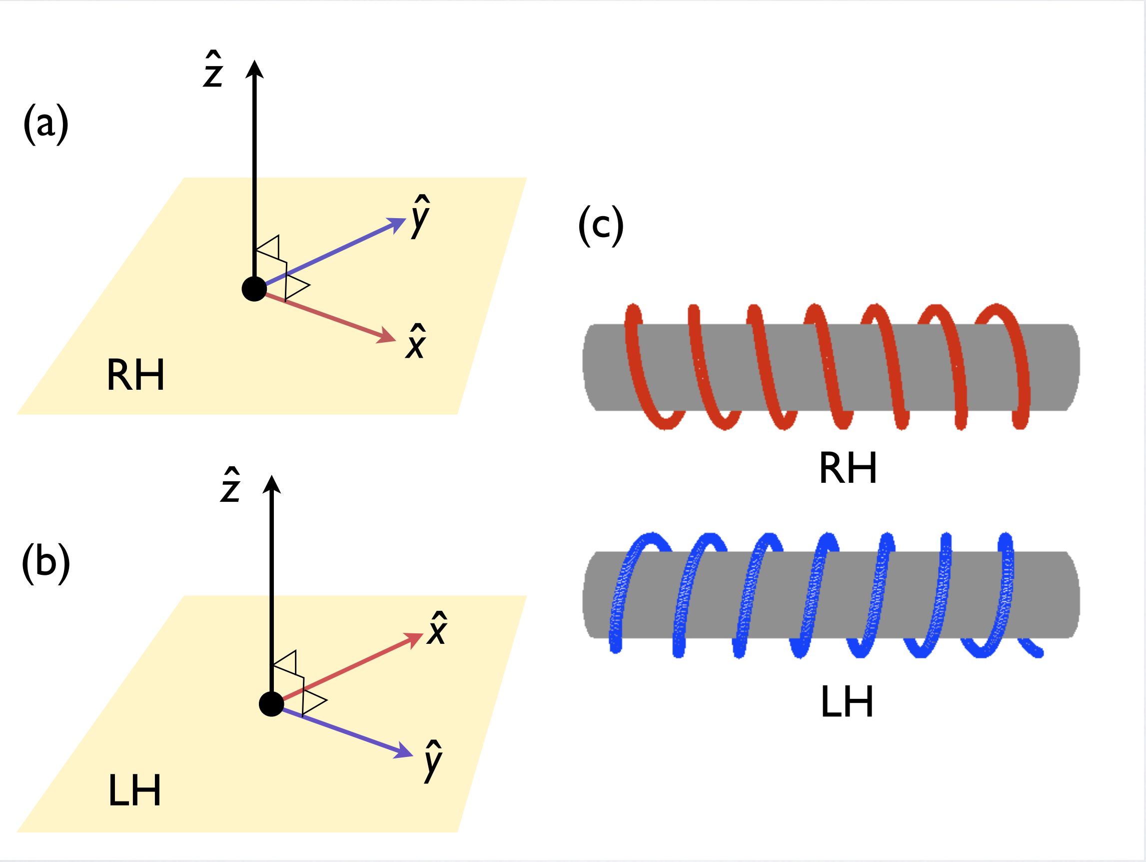
FIGURE 1.16
Showing that the flux through any closed surface qround q is the same as the flux through the sphere.

GEOMETRIC INTERPRETATION

- Gauss' law is just the divergence theorem
  - sources + sinks in closed volume = **div** = flow
  - same law in fluid dynamics (*i.e.*, plumbing)
  - charge is source of E
  - flow of field (lines) out of a volume = net charge
- Gauss for magnets gives zero
  - *sources* are discontinuities in the (scalar) potential, currents

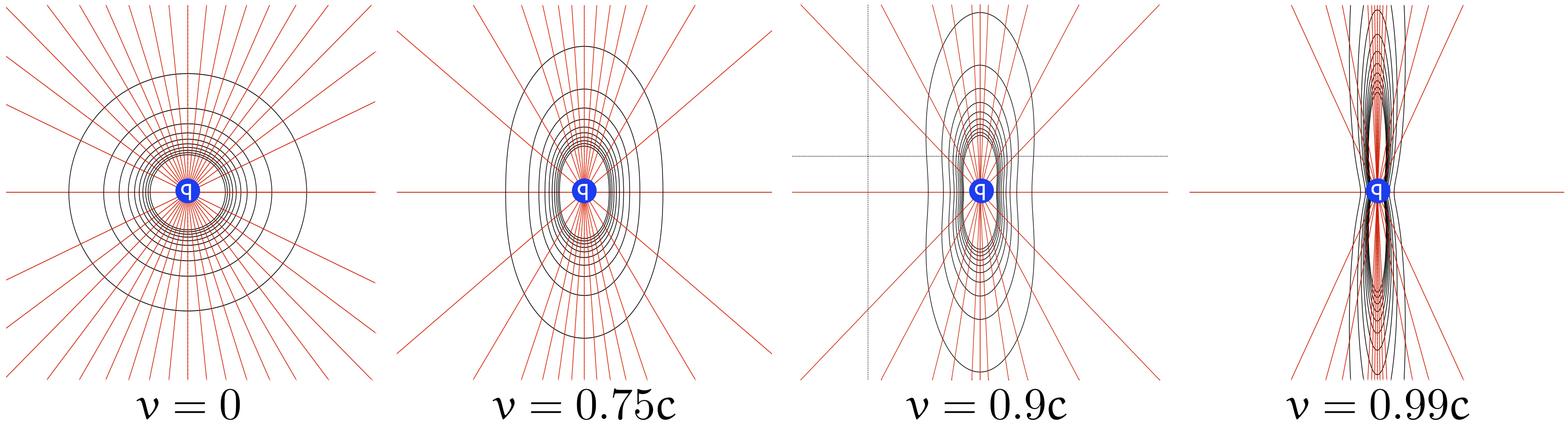
handedness

- B is a pseudovector ...
- like a vector under proper rotation
- picks up '-' under improper rotation (inv + rot)
- thus we have a choice of handedness

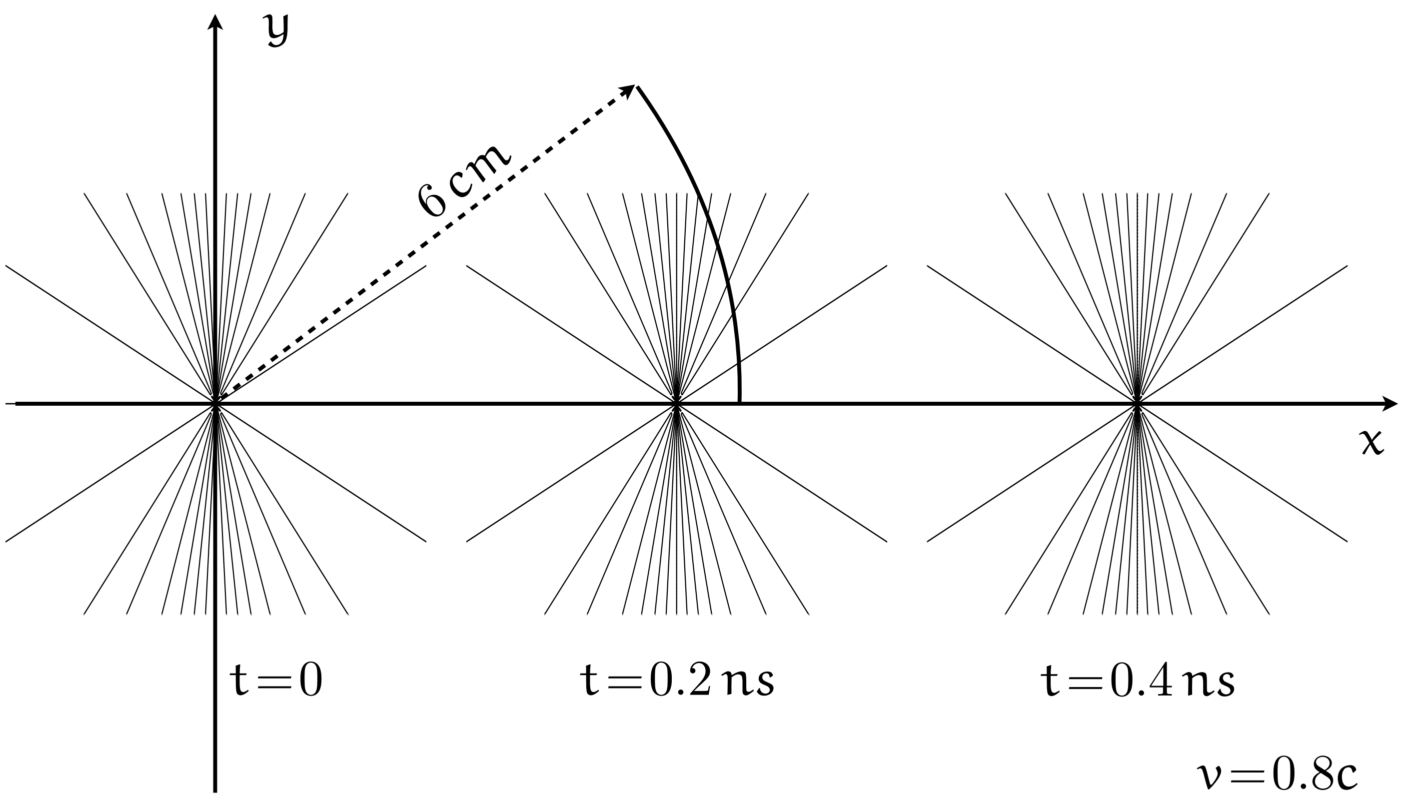


	SI units	CGS units
Energy	1 Joule	10^7 erg
Force	1 Newton	10^5 dyne
Electric Charge	1 Coulomb	"3" x 10^9 esu
Electric Current	1 Ampere	"3" x 10^9 esu/sec
Electric Potential	"3" x 10^2 Volts	1 statvolt (erg/esu)
Electric Field	"3" x 10^4 Volts/m	1 statvolt/cm (dyne/esu)
*Magnetic Field **B***	1 Tesla	10^4 gauss (10^4 dynes/esu)
*Magnetization **M***	1 Ampere/m	4π x 10^{-3} Oersted
*Magnetization **M***	1 Ampere/m	10^{-3} emu/cm^3
*Magnetic Field **H***	1 Ampere/m	4π x 10^{-3} Oersted
Capacitance	1 farad	"9" x 10^{11} cm
Resistance	1 ohm	1/("9" x 10^{11}) sec/cm
Inductance	1 henry	1/("9" x 10^{11}) sec^2/cm

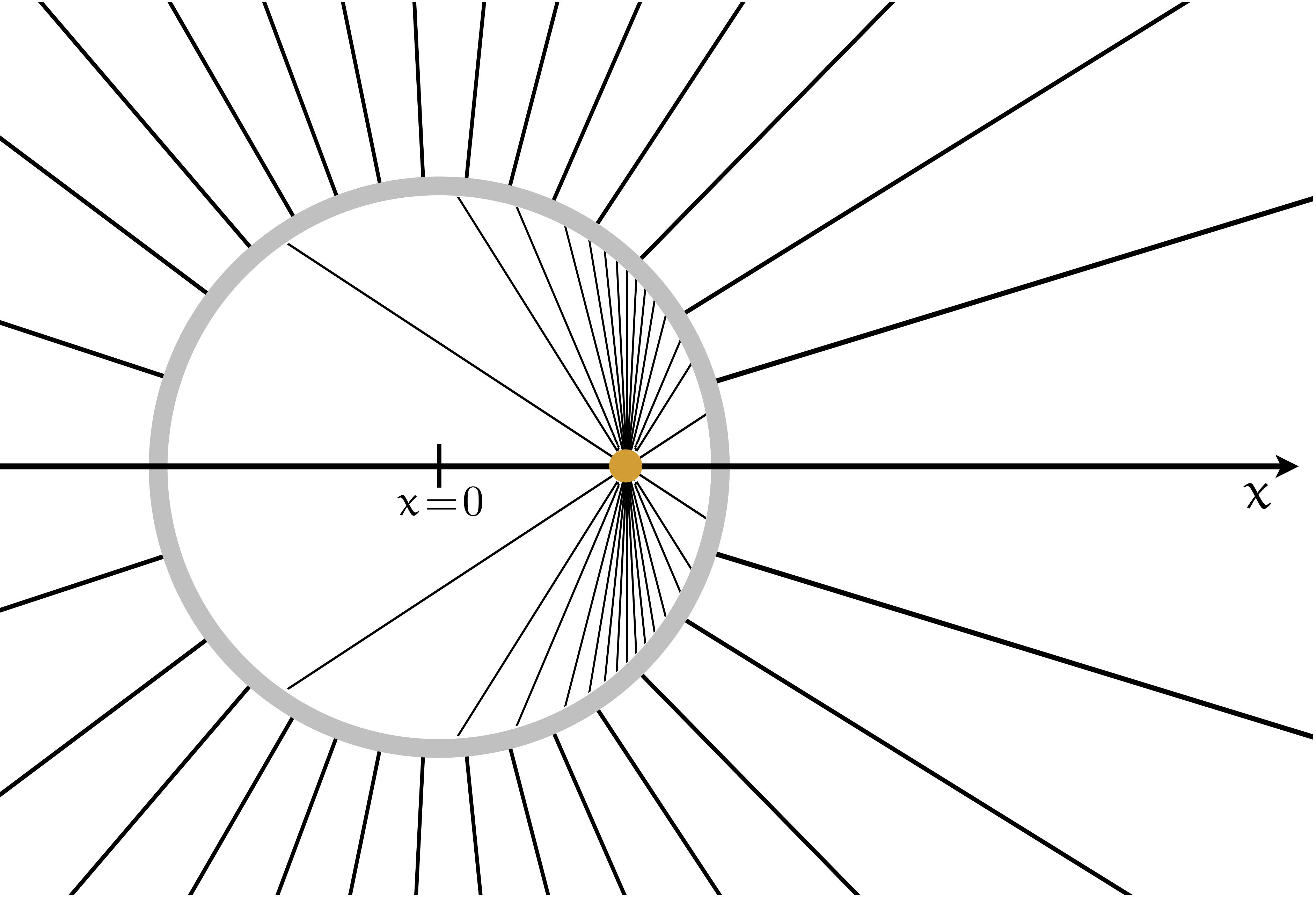
"3" = 2.9979 "9" = "3" x "3"



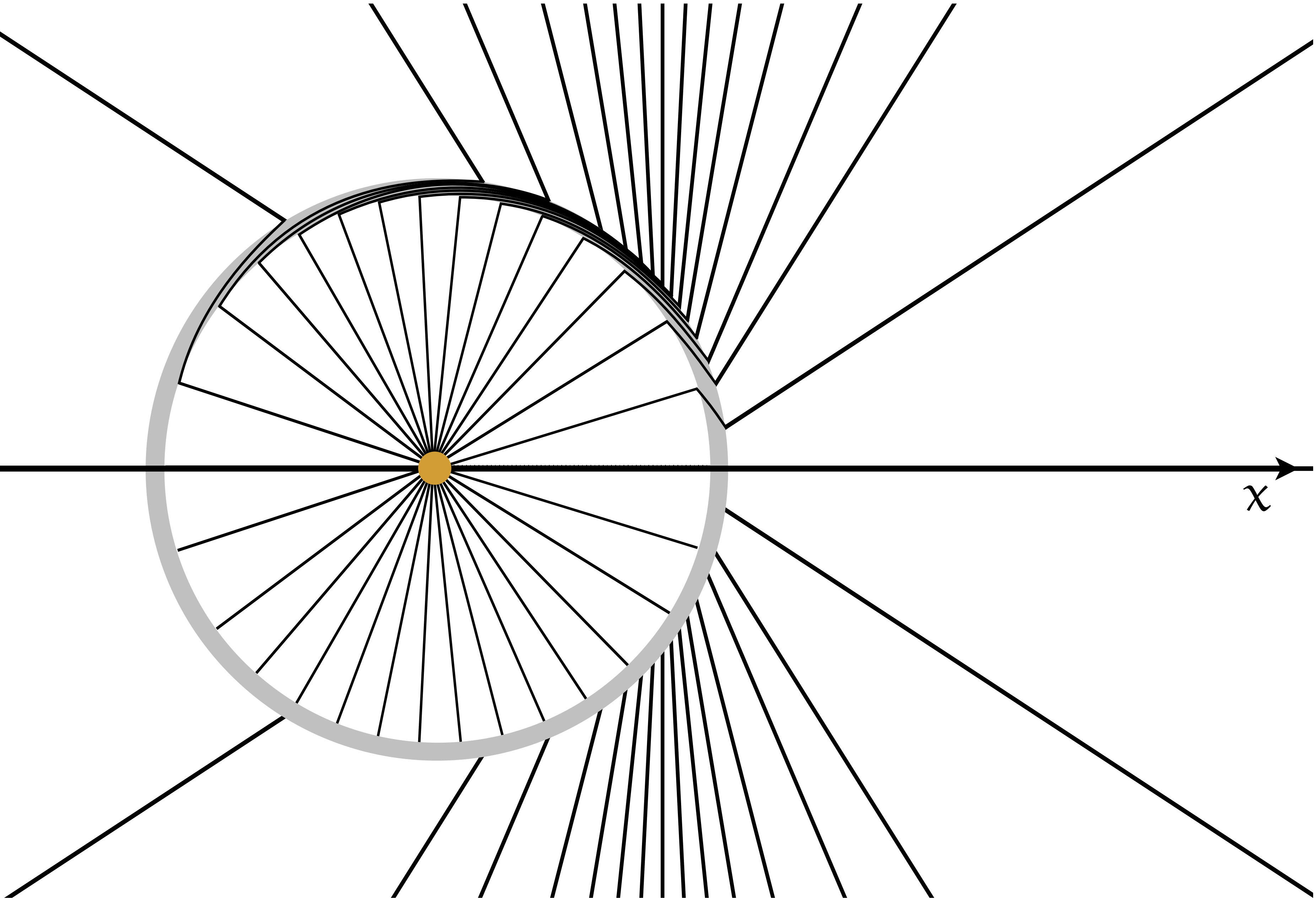
q
v = 0
v = 0.75c
v = 0.9c
v = 0.99c



y
6 cm
x
t = 0
t = 0.2 ns
t = 0.4 ns
v = 0.8c

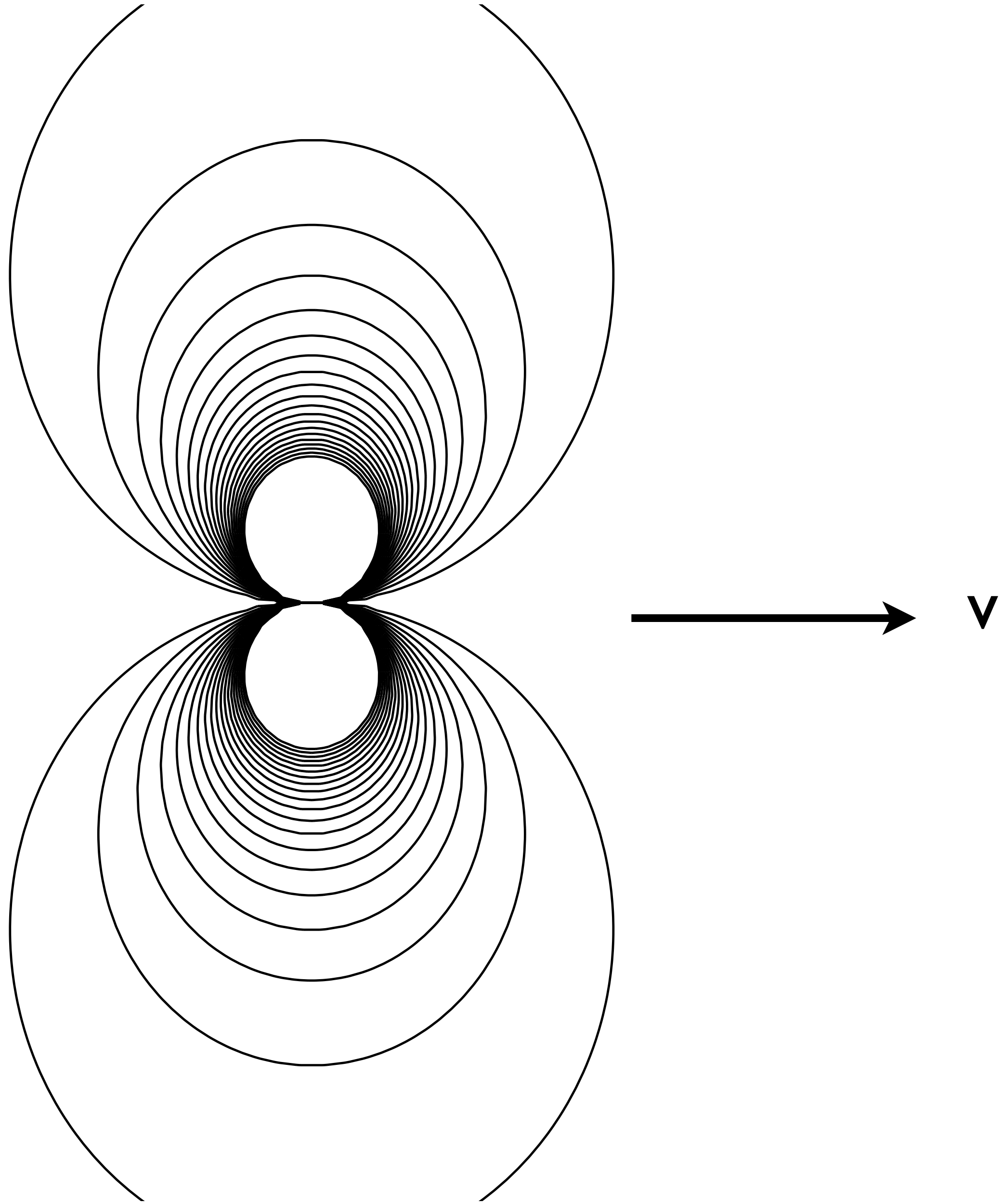


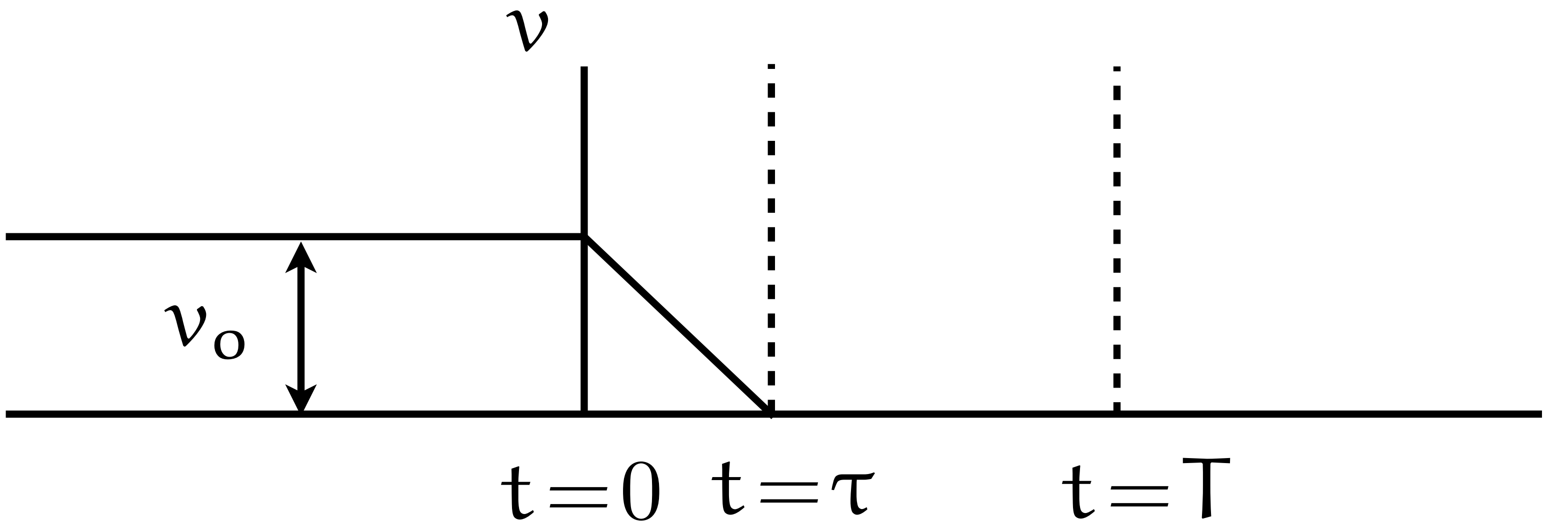
x = 0
x


x

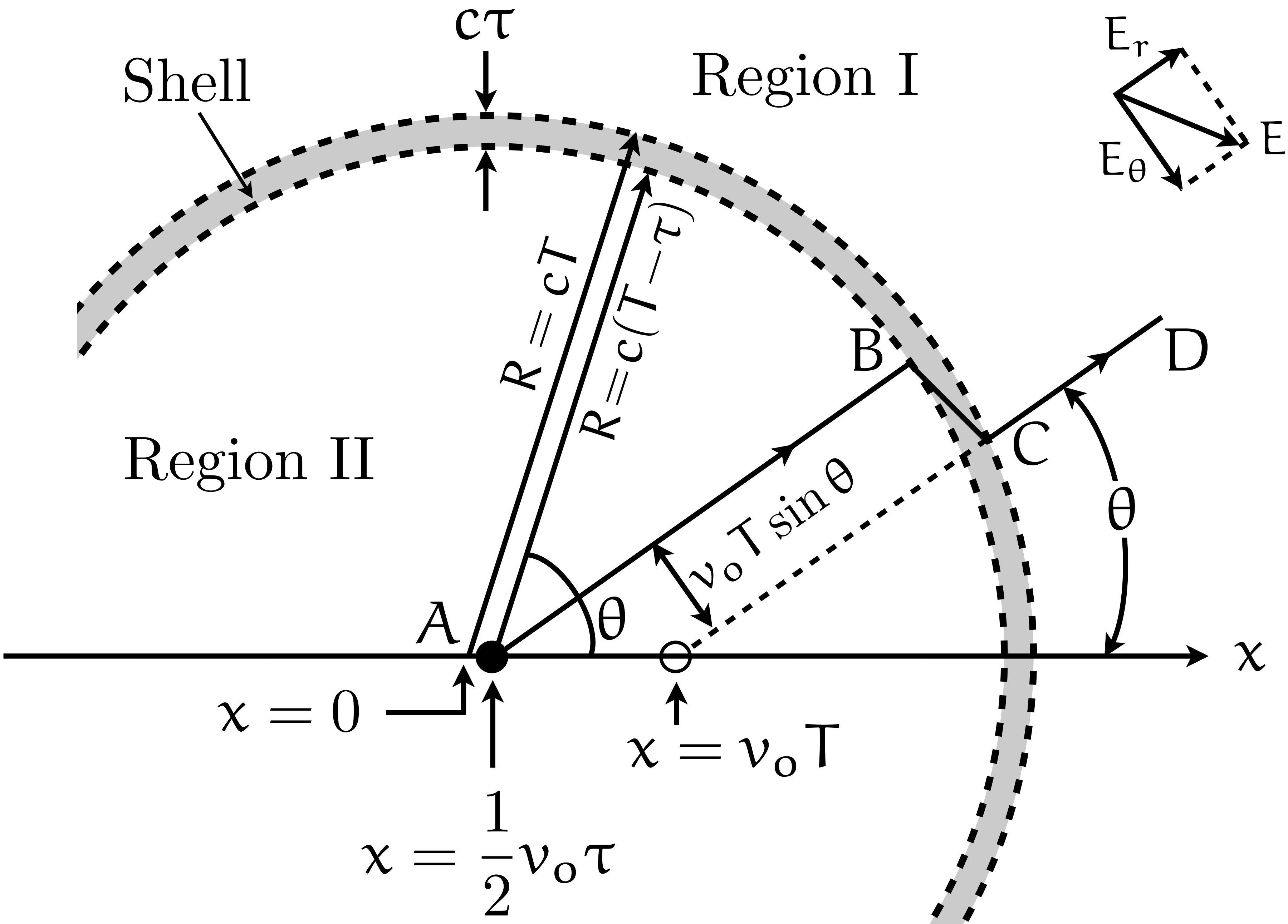
Animations ...

- http://webphysics.davidson.edu/applets/retard/Retard_FEL.html
- ‘retarded’ means ‘field from where the charge was a time t=r/c ago’

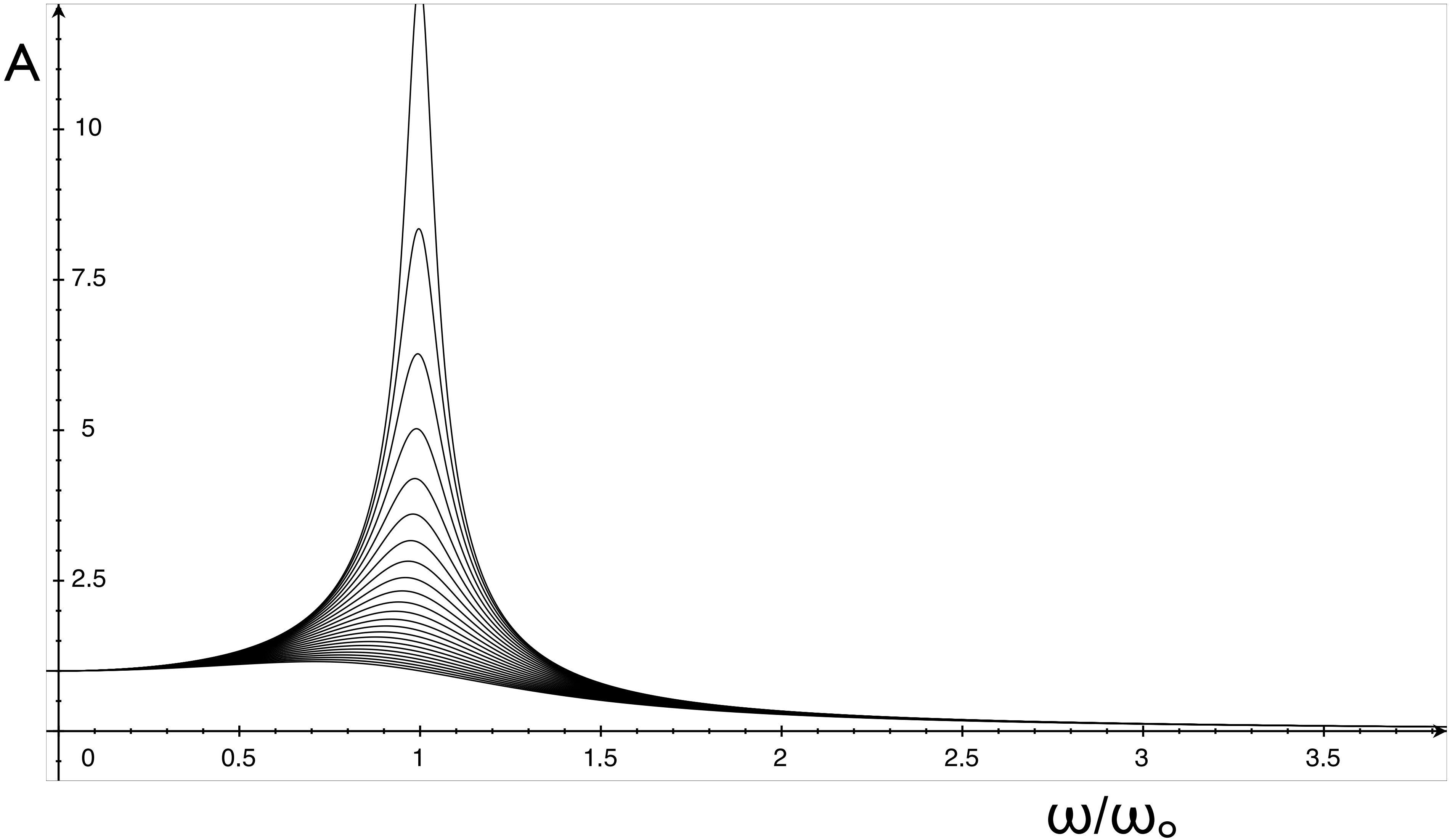

v

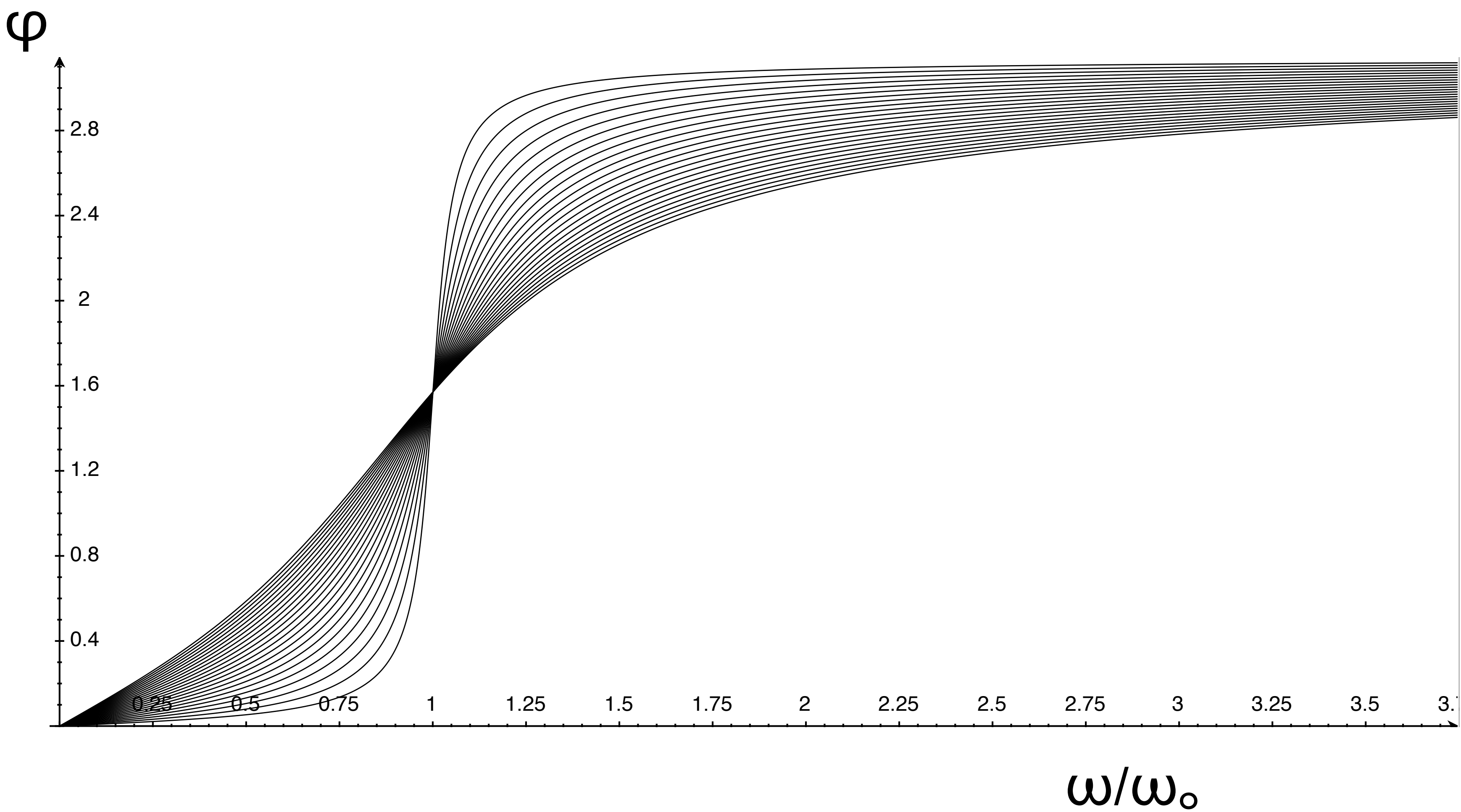


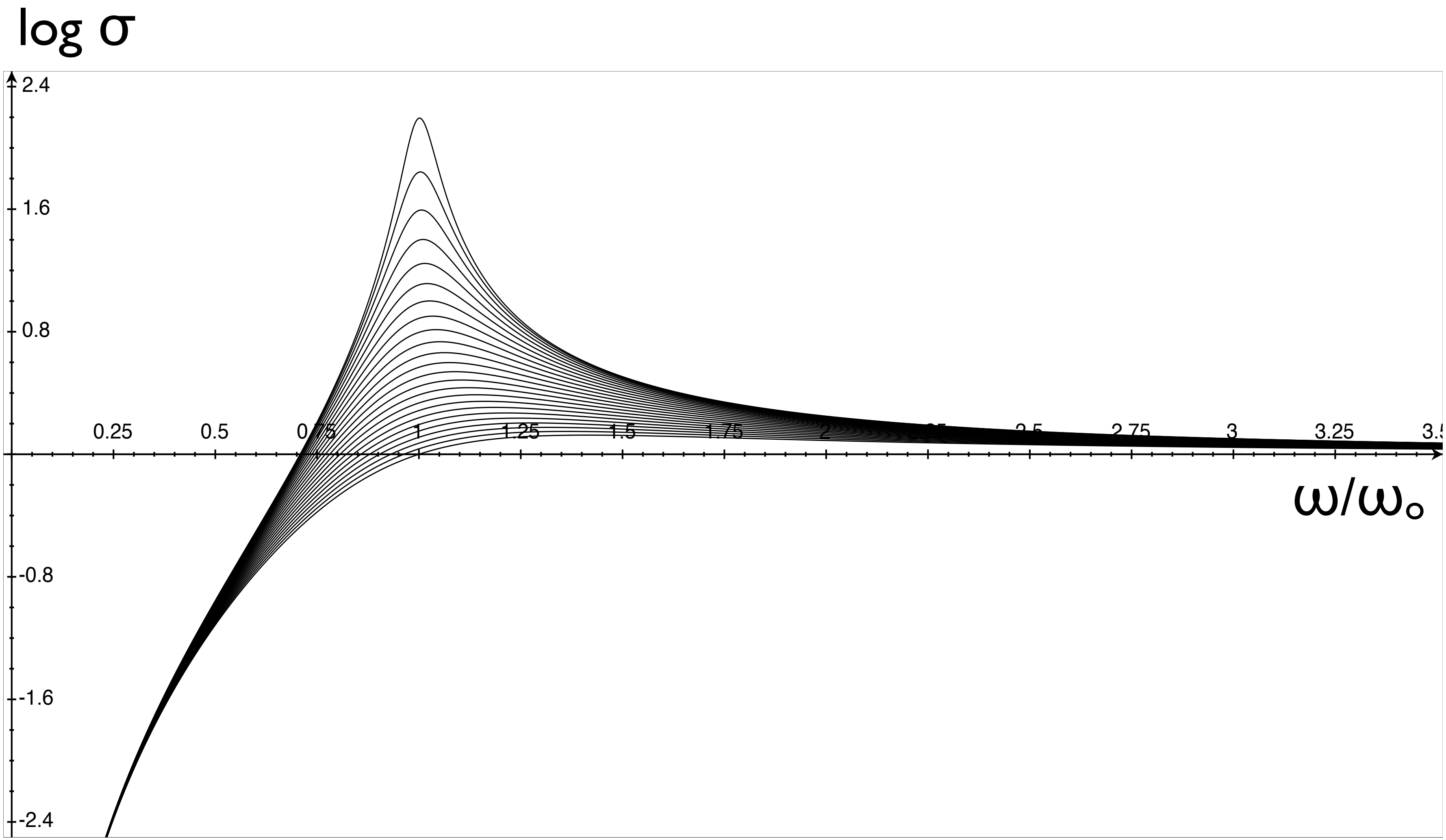
v
v_o
t = 0
t = τ
t = T



cτ
Shell
Region I
Region II
E_r
E
E_θ
R = cT
R = c(T − τ)
B
C
D
A
θ
$v_o T \sin\theta$
θ
x
x = 0
x = v_oT
x = $\frac{1}{2} v_o \tau$


A
10
7.5
5
2.5
0
0.5
1
1.5
2
2.5
3
3.5
ω/ω₀


φ
2.8
2.4
2
1.6
1.2
0.8
0.4
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
3.25
3.5
ω/ω₀


log σ
2.4
1.6
0.8
-0.8
-1.6
-2.4
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.5
2.75
3
3.25
ω/ω₀