Notes for

Electric Fields & Potential Mapping

1) ~~Electric~~ Fields

— a field in physics is a quantity that has a value at every point in space or some specified region of space

— a scalar field is one where there the field just has a value at every point in space

e.g., density, temperature, pressure

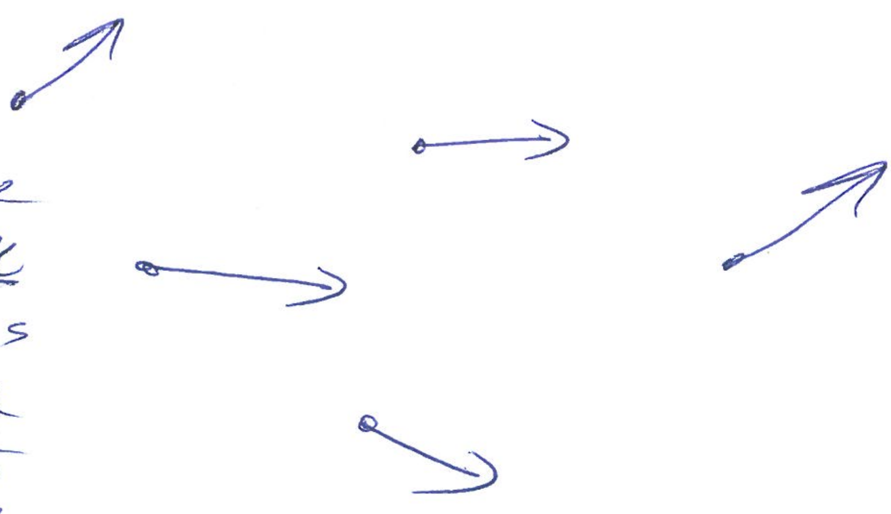
The value can be positive or

negative — so it's not just a magnitude. (e.g., Celsius temperature) But the quantity has no direction assigned to it.

- A vector field has a magitude and a direction.

I think of <u>little arrows</u> attached to each point in space.

The arrows point in ordinary 3-d space but <u>their extent</u> is their own abstract space.



Of course, there is a continuum infinity of such arrows — so one can only draw a representative sample which in mapping can be made large enough to allow the whole field to be visualized by interpolation.

2) The Electric Field

The electric field (E-field) in one sense extends throughout space and is singular.

4)

But particular regions of this ~~E~~ universal $\mathbf{E}$-field can have their own special structure and rather than refer to them as $\mathbf{E}$-field regions, we just call them $\mathbf{E}$-fields for particular systems.

~~The E fi~~ Context decides which is meant.

The $\mathbf{E}$-field is the cause of the electric ~~oe~~ force

For a point charge q

$$\underset{\sim}{F} = q\underset{\sim}{E}$$

unit of $\mathbf{E}$-field

$$\frac{N}{C} = \frac{V}{m}$$

volt per meter

is the ~~charge~~ electric force on q.

— the electric field has an associated energy density and variations in the E-field propagate thru vacuum at the vacuum light speed.

— The electric field is a real thing, not a mathematical auxiliary, in electromagnetism.

— The E-field can be caused by charge.

For a point charge q

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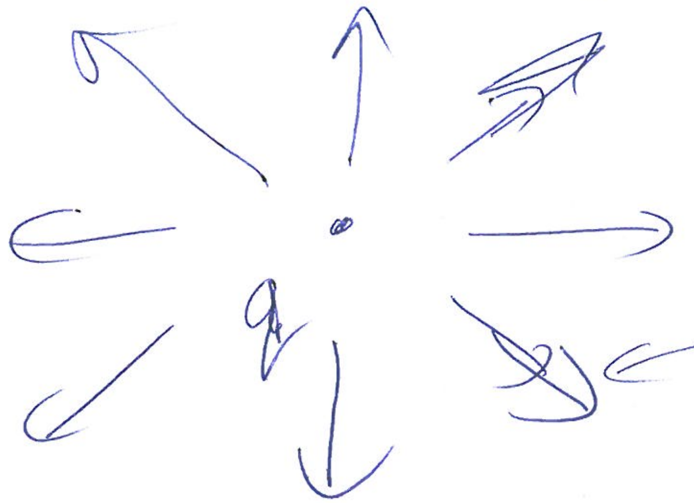
$$\underset{\sim}{E} = \frac{kq}{r^2}\hat{r}$$

with the origin at the point charge.



E-field vectors

– Recall they point in ~~real~~ physical space but extend in their own abstract E-field space.

Their length is their strength

The E-field of collections of point charges can be calculated by adding up with vector addition the E-fields of the individual charge.

An E-field can also be caused by

a time varying magnetic field without charge

This effect is described by Faraday's law of induction (well the Maxwell-Faraday version)

We will get to that in a later lab

The E-field in one sense is invisible to the human eye

but in another sense it's half of all we do see.

— light is a self-propagating coupled electromagnetic field.

The electromagnetic field being a coupled (i.e., interacting) electric & magnetic field

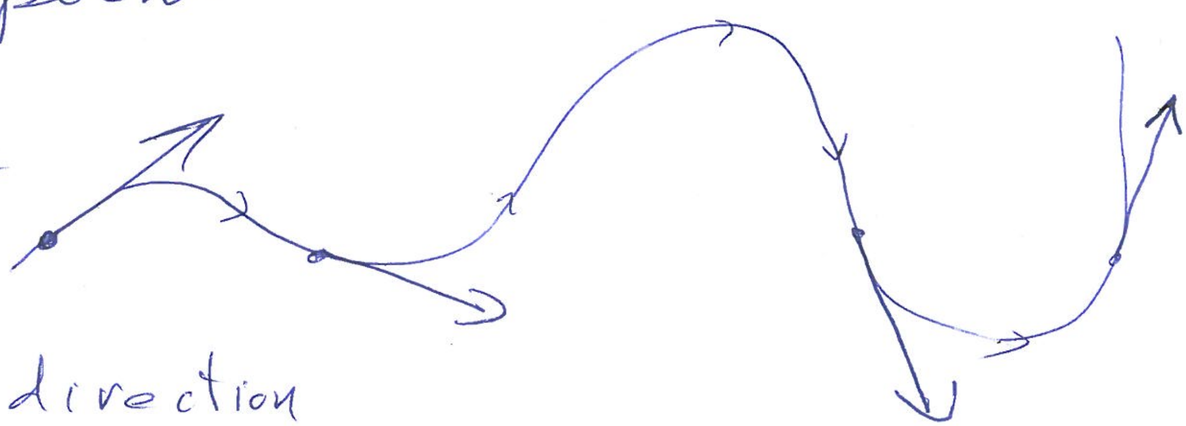
OR the E-field & magnetic field considered jointly.

3 Field Lines

In mapping an visualizing E-fields (and other vector fields too), one can use field lines (introduced by Faraday — what a guy.).

The idea is to draw a continuous line (but not a straight one in general) that is tangent at every point in space to the E-field at that point

Example



The direction of the field is that of the tangent E-field vectors.

Question

Can field lines ever cross?

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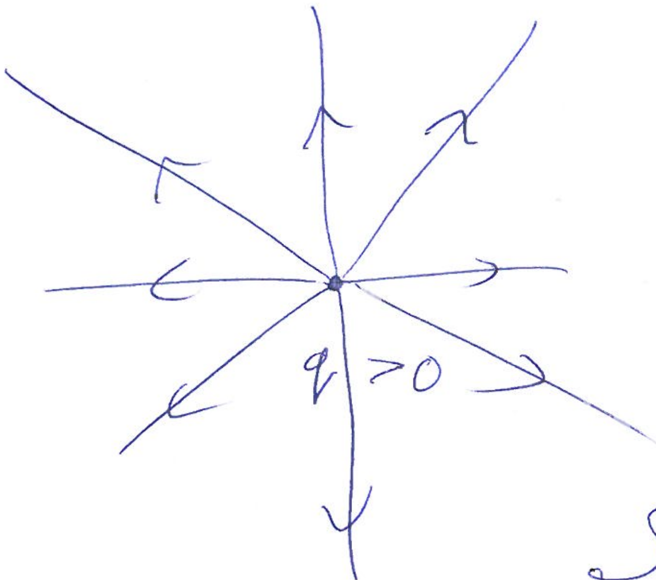
Ans **No** & **Yes** (sort of)

No field lines cannot cross because to cross the E-field would have to point in two directions at one point which is impossible

Yes (sort of) If the E-field goes to zero at a point, then one can sort of say E-field lines cross there or alternatively end there. ~~Well~~ We'll see ~~consider~~ this in an ~~some~~ examples below.

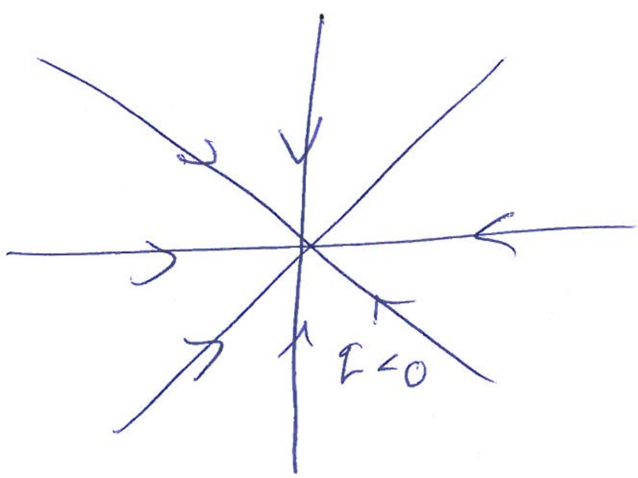
Example E-fields

a) Point charges — isolated one



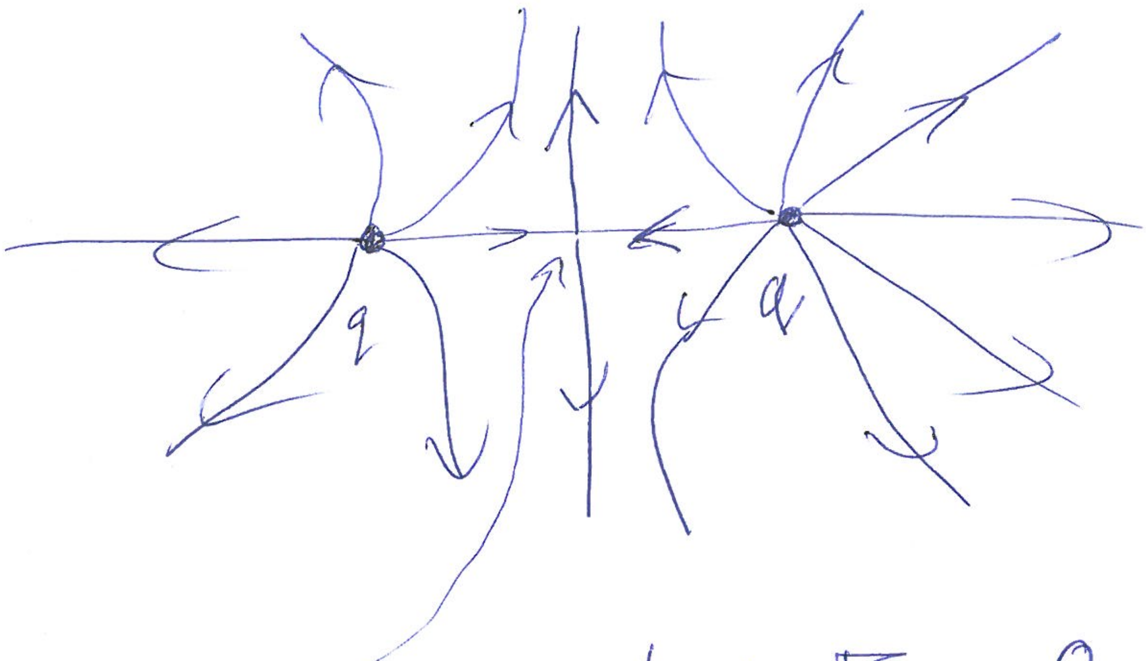
Field lines start on positive charge and extend to infinity

one is only looking at a <u>planar</u> slice of space here and one ~~can't~~ can only draw a representative set of field lines



Field lines end on negative charge and come in from infinity.

b) <u>Two equal positive charges</u>



by symmetry $\underset{\sim}{E} = 0$
and the field lines
<u>cross</u> or <u>end and start</u>
here depending on
your point of view.

- up close to either charge
each has a point-charge
E-field for a charge q

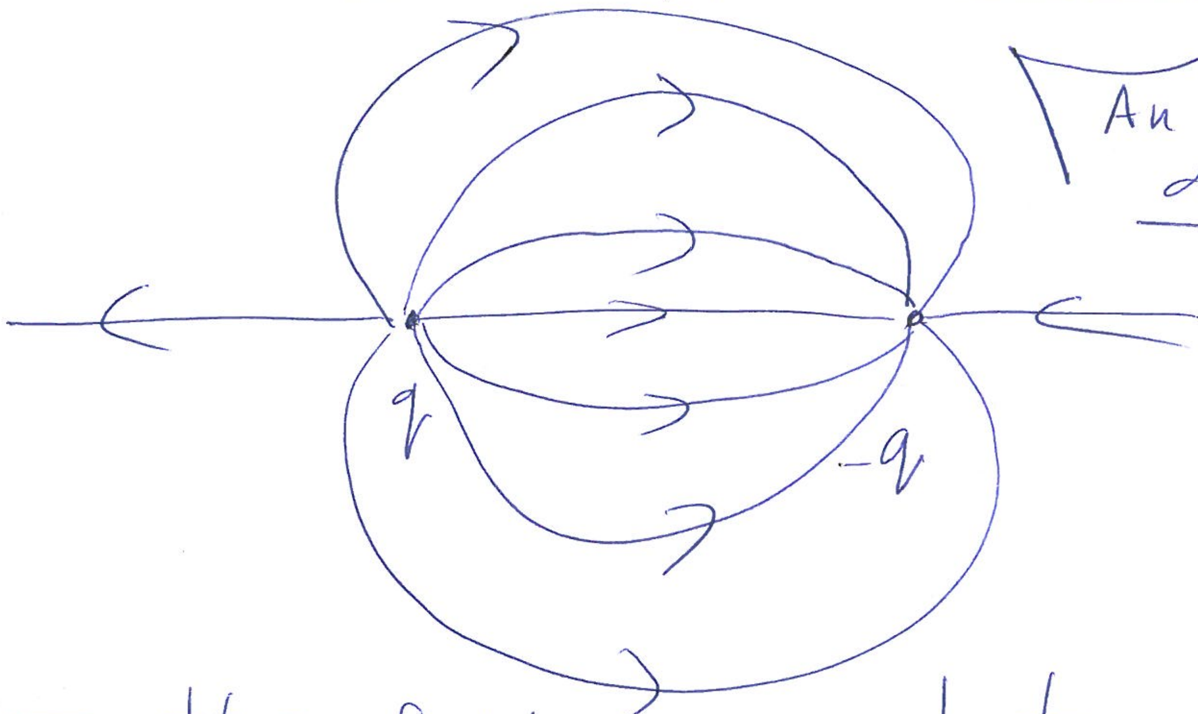
- far away from both
the E-field approaches

that of a point charge of charg 2q located at the center of symmetry.

In between one interpolates.

c) Two point charges of equal magnitude and opposite sign

An electric dipole



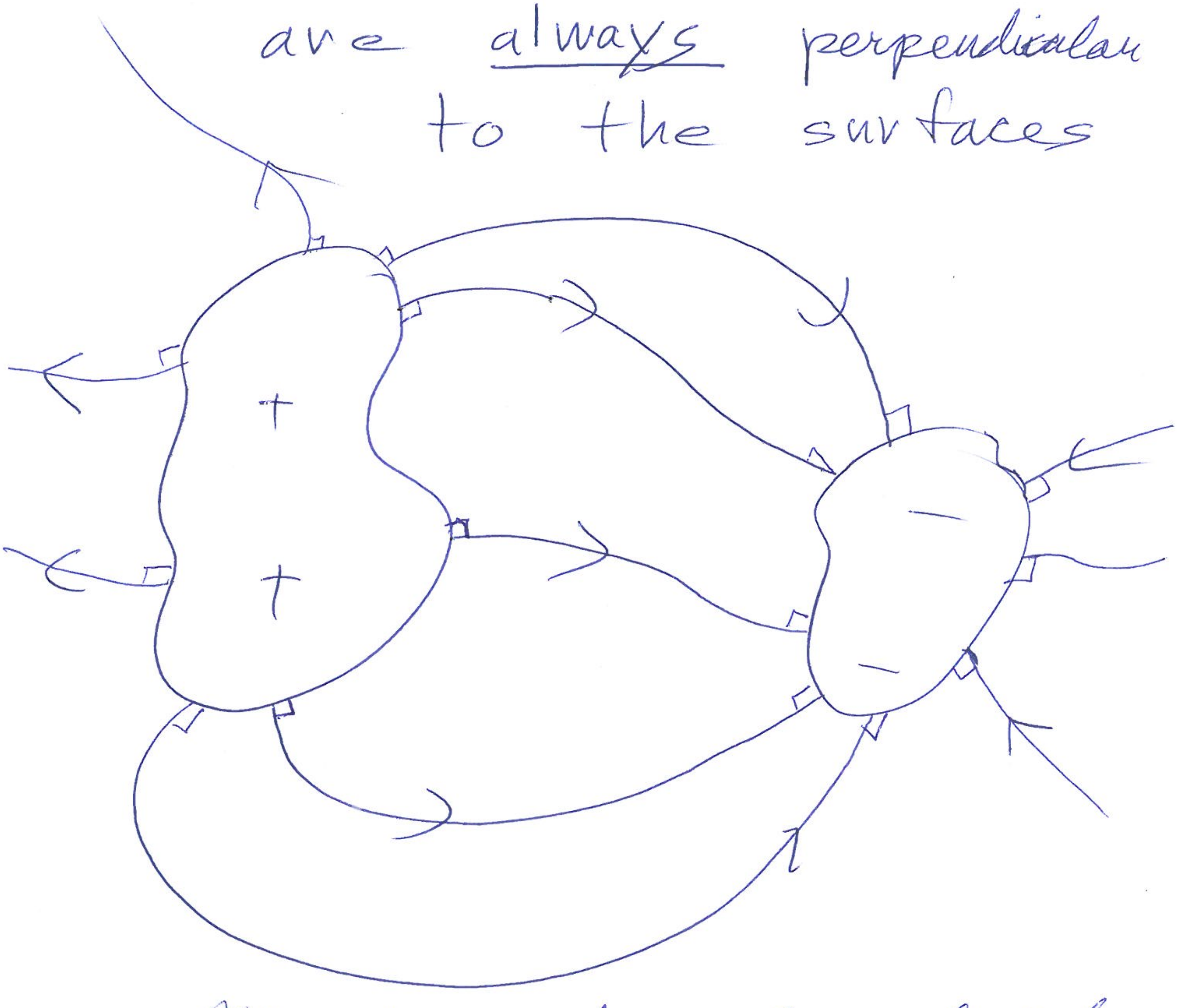
— the field has rotational symmetry about the symmetry axis

— in a planar ~~the dipole~~ slice the dipole field has a butterfly shape

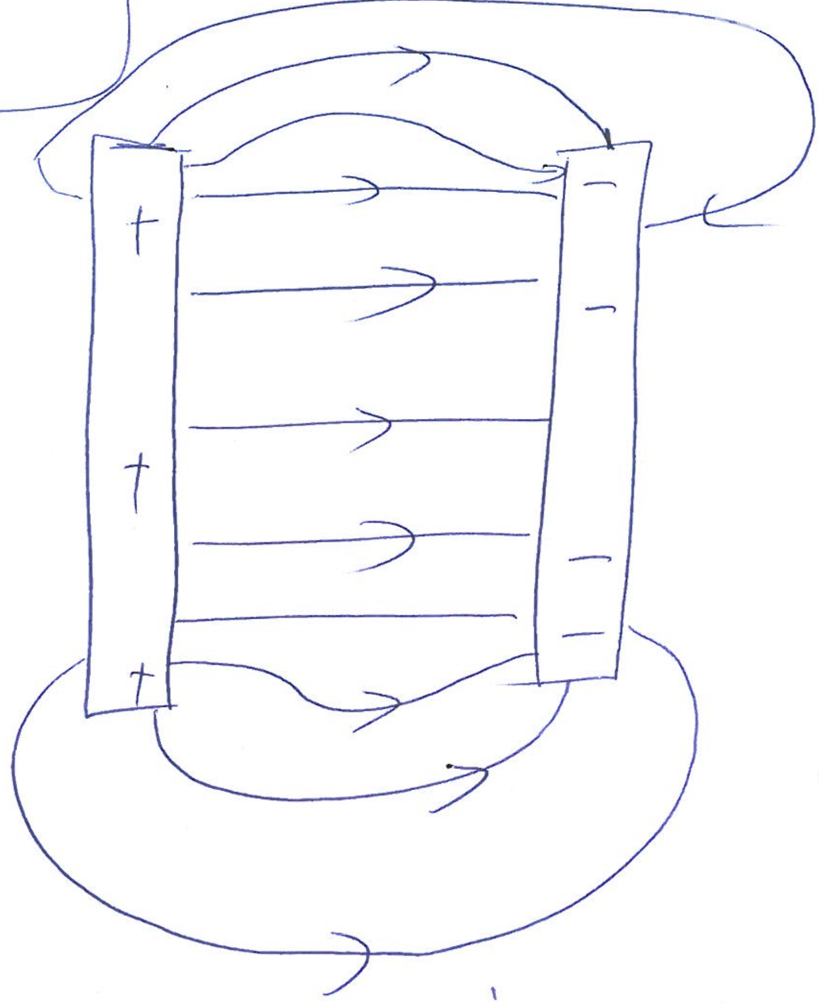
— at far field, the dipole field never looks like a monopole field (i.e., the field of one point charge)

d) Equipotential surface of electrostatic or at least constant potential conductors

— We'll discuss equipotentials below, but the key point for visualizing the field lines is that field lines are <u>always</u> perpendicular to the surfaces



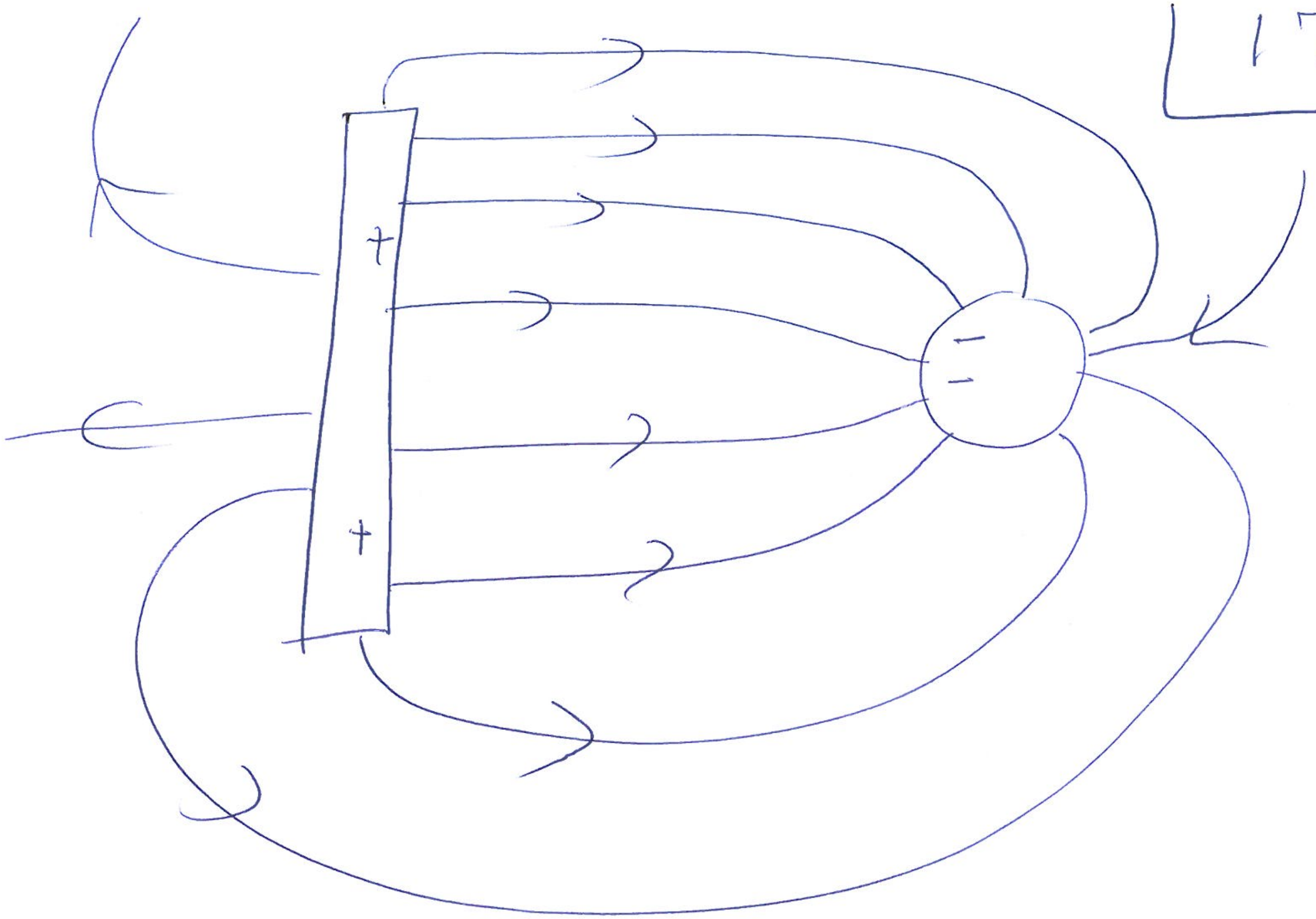
The shape of such a field can often be estimated by interpolation.



This is ~~sort~~ of a parallel plate capacitor.

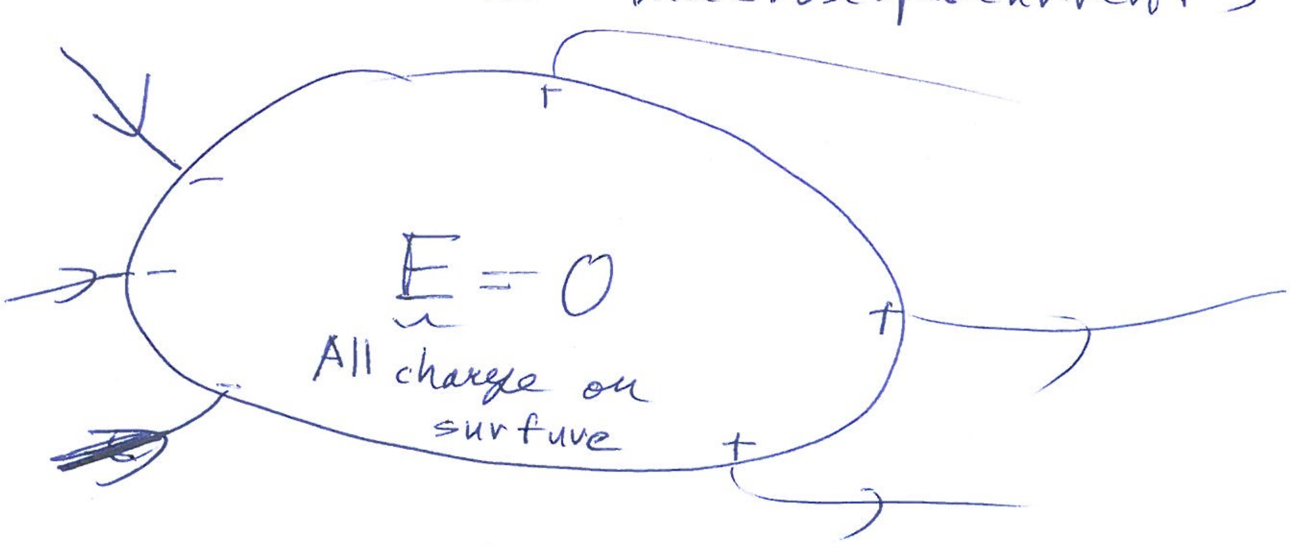
The field is strong between the plates and weak outside.

In the center region between the plates, the E-field is nearly uniform — i.e., nearly constant in direction and magnitude



e) $\underline{E}$ - field inside an electrostatic conductor

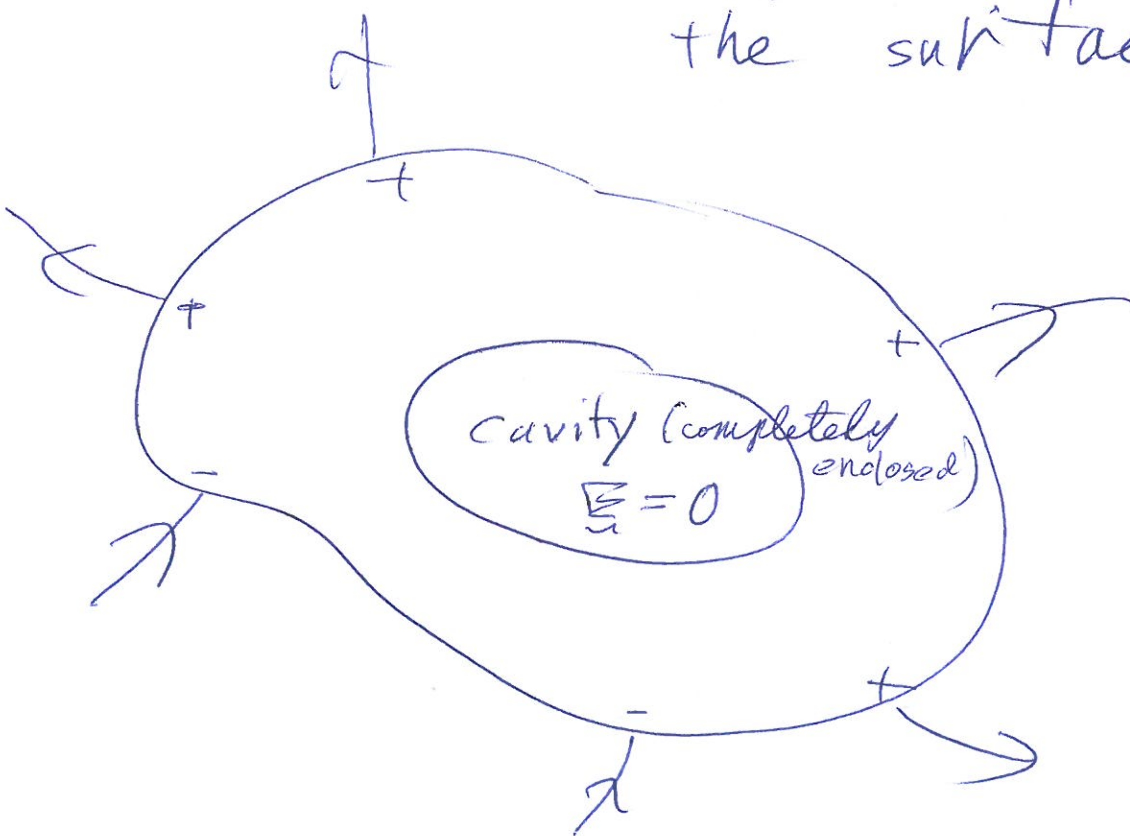
~~no char~~
no macroscopic currents



microscopic fields of electrons and atoms vary strongly but average to zero over macroscopic distances,

The macroscopic $\underline{E}$-field is zero inside and over macroscopic regions the inside is neutral.

All net charge or separated charge is on the surface.



Strictly $\underset{\sim}{E} = 0$
in cavity
only when the
situation is <u>electrostatic</u>

No currents, no
changing external
fields

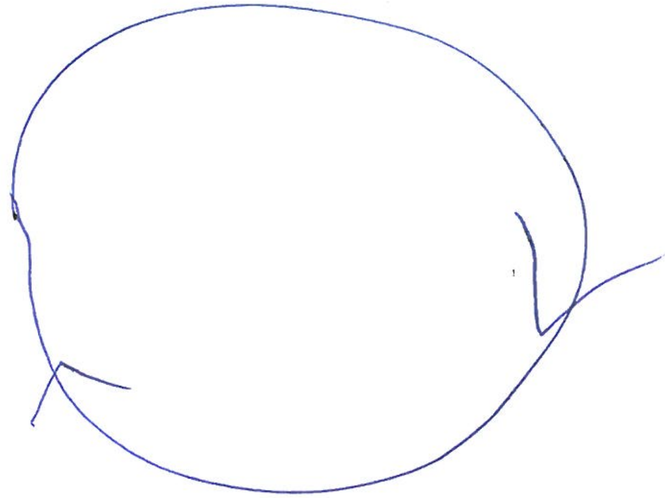
<u>But</u> in practice
the field is often nearly
<u>zero</u> inside even
when there are external
changing E-fields
and when <u>the cavity</u>
has holes to the
outside.

20)

As a ~~device~~ device such a cavity is a Faraday ~~shield~~ Cage and is use to shield from external E-fields

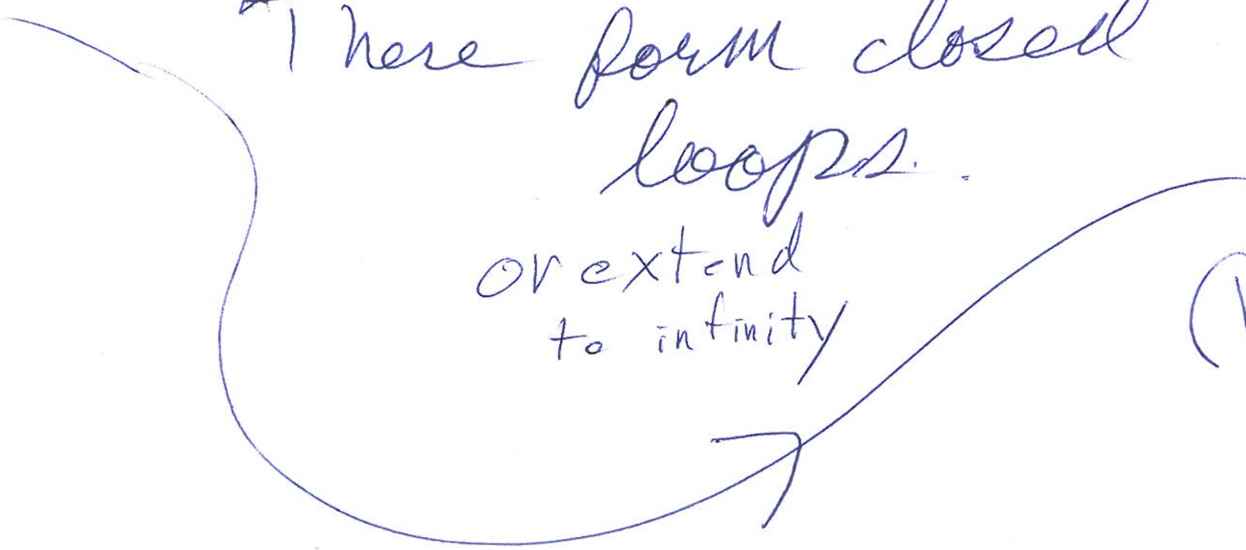
- if grounded the cage will shield the outside world from fields in the cavity caused by charges put there.

~~d~~) Faraday law - induced E-fields caused by changing magnetic fields



These form closed loops.

or extend to infinity



(Wik: field line)

No charges cause these (in a direct sense)

4) Potential

— some E-field structures, but

<u>not</u> all
(Not Faraday law-induced
$\vec{E}$-fields — without
being tricky)

allow <u>potential energy</u>
to be defined.

<u>Potential energy (PE)</u>
is the <u>energy</u>
<u>of position</u> associated
with a charge located
in the <u>$\vec{E}$-field</u>,

at a more basic level
this is energy of
the $\vec{E}$-field structure,

but that is
a tricky way
to deal with the
energy
— the E-field structure
energy is ~~all~~ always
there
— PE is a <u>quick way</u>
to deal with that
energy when PE
can be defined.

<u>Potential</u> is PE per
(symbol V) unit
charge.

<u>So</u> potential is NOT
something associated
with ~~the charge~~
particular charges

but is associated with the E-field itself.

It's very useful (and arguably completely correct) to view potential as being landscape with hills and valleys and planes.

of course the height of this landscape is in a abstract space

— at every point in the region where the potential is definable there is a "height"

Potential is, in fact, a scalar field

given the symbol V { Italic since a variable

and the MKS unit is the volt (symbol V { Roman since a unit.

(potential is often called voltage, but not in physics books)

~~and voltage actually~~

The zero point of potential is arbitrary and is chosen for convenience.

Only changes in potential affect anything (aside from potential itself).

26)

If a point charge q goes through a potential change ΔV,

then there is ~~an~~ PE ~~energy~~ change

$\Delta PE = q\Delta V$ } Going "uphill" for a +ve charge

If $q\Delta V > 0$, energy goes into PE (into electric field structure)

If $q\Delta V < 0$, energy comes out of PE (~~out~~ out of E-field structure)

going "downhill" for a positive charge.

Where does the PE energy come from or go to?

That depends.

If only the electric force is present, the energy comes from the ~~particles~~ ~~charges~~ charge's kinetic energy or goes to it.

In circuits, the PE can go into waste heat or mechanical work or other things.

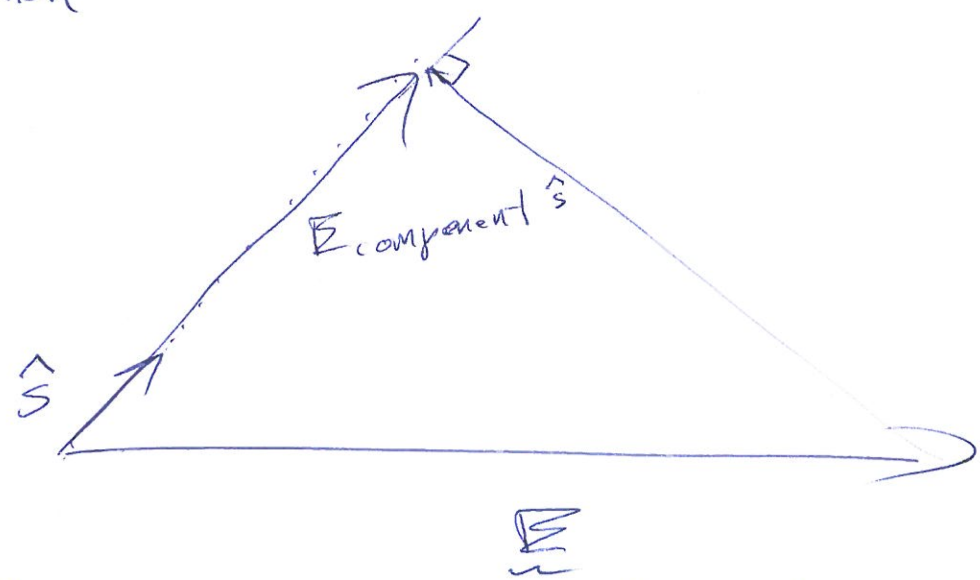
It can come from an EMF (we'll discuss later) or other things.

5) Potential & Electric Field

Potential is derivable from the E-field and vice versa.

Here we only need the equation

$$E_{\text{component in } \hat{s} \text{ direction}} = \underset{\sim}{E} \cdot \hat{S} = -\frac{dV}{ds} \doteq \frac{\Delta V}{\Delta s}$$



Note $\underset{\sim}{E}$ and $\underset{\sim}{E}_{\text{com } \hat{s}}$ have extend ~~into~~ in abstract space only.

~~The~~

Getting V from $\mathbf{E}$ takes an integral

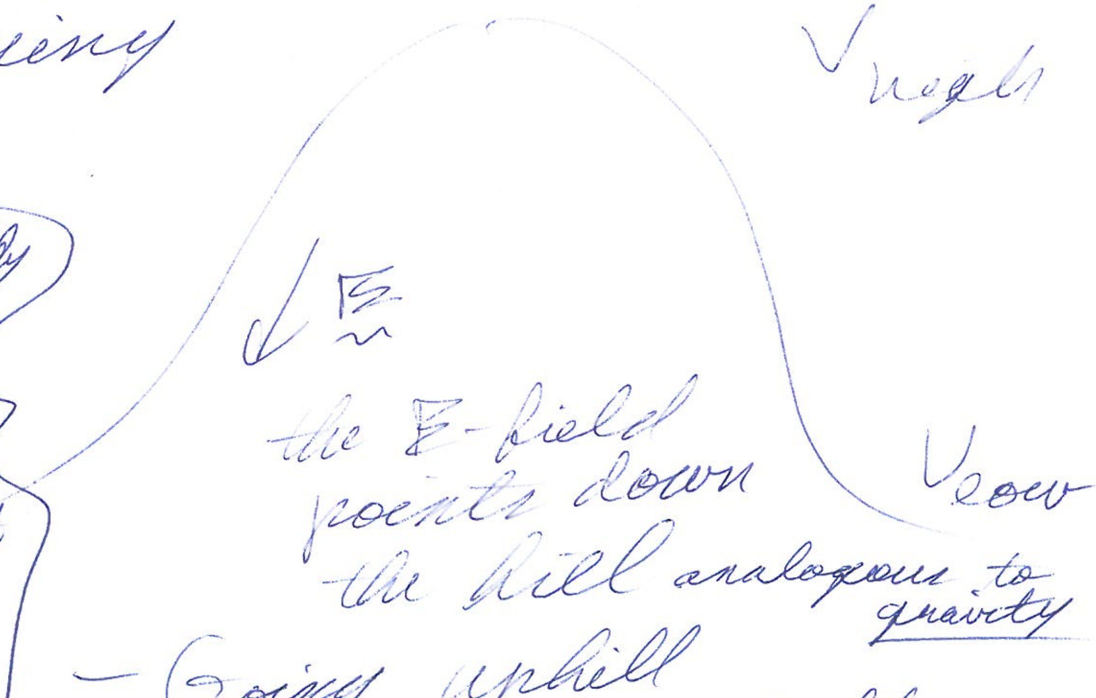
$$\Delta V_{ab} = -\int_a^b \mathbf{E} \cdot d\mathbf{r}$$

The minus sign is mathematically annoying, but is physical clarifying

dot product

differential displacement

Potential hill



$\mathbf{E}$ is actually ~~the fastest~~ points down the fastest path of descent at any point.

the E-field points down the hill analogous to gravity

- Going uphill against the

E-field increases the potential

For a differential change

$$dV = -\underset{\sim}{E} \cdot d\underset{\sim}{s}$$

$$= -\underset{\sim}{E} \cdot ds\,\hat{s}$$

or $$\underset{\sim}{E} \cdot \hat{s} = -\frac{dV}{ds}$$

and so we have recovered the result of p. 28a and verified it

Rate of decrease of V with distance is most rapid along the path of $\hat{s}$ aligned with $\underset{\sim}{E}$

[In vector calculus $\underset{\sim}{E} = -\nabla V$
where ∇V is the gradient of V.]

Ideally to measure $\vec{E}$ component in $\hat{s}$ direction you should measure the derivative $\frac{dV}{ds}$ of V in the $\hat{s}$ direction.

In our experiment, we approximate

$$\frac{dV}{ds} \simeq \frac{\Delta V}{\Delta s}$$

finite change in ΔV over a finite displacement.

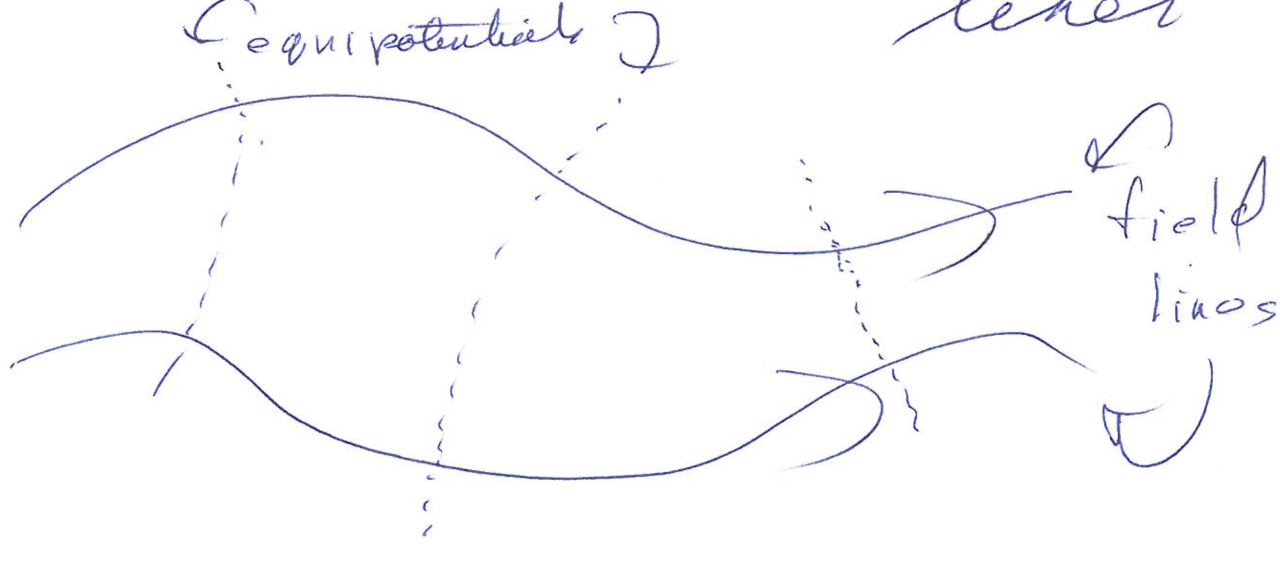
If $\frac{dV}{ds} = 0$

then $\vec{E}$ component in $\hat{s}$ direction $= 0$

The $\underline{E}$ ~~veto~~ vector is perpendicular to the direction where V is constant.

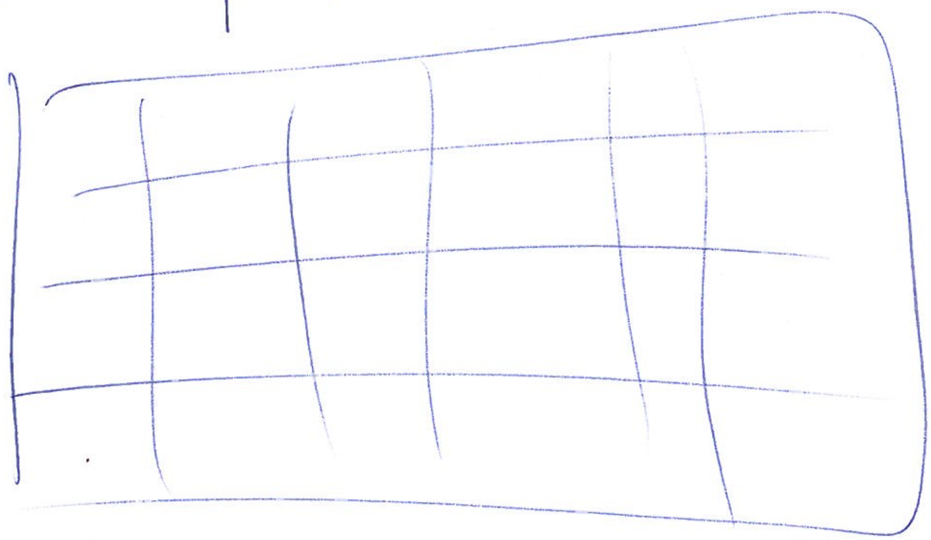
So surfaces of constant V

or ~~[illegible]~~ equipotentials are always perpendicular to the $\underline{E}$-field and the ~~[illegible]~~ field lines



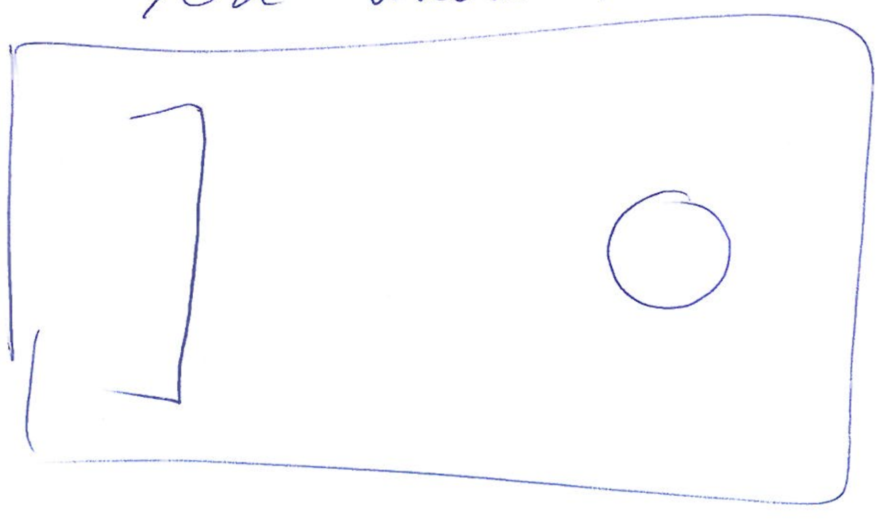
6) Our Experiment

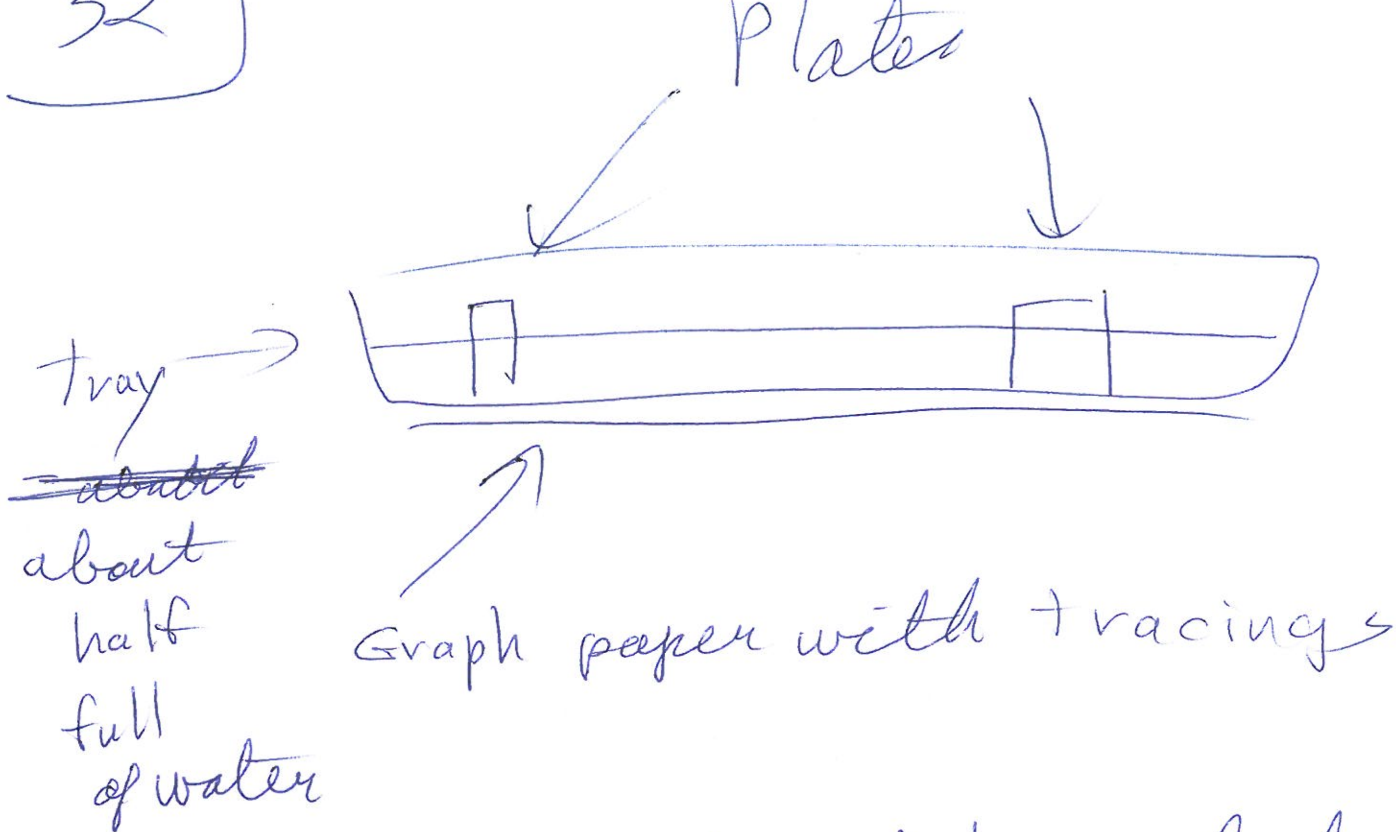
→ sheet of Graph paper



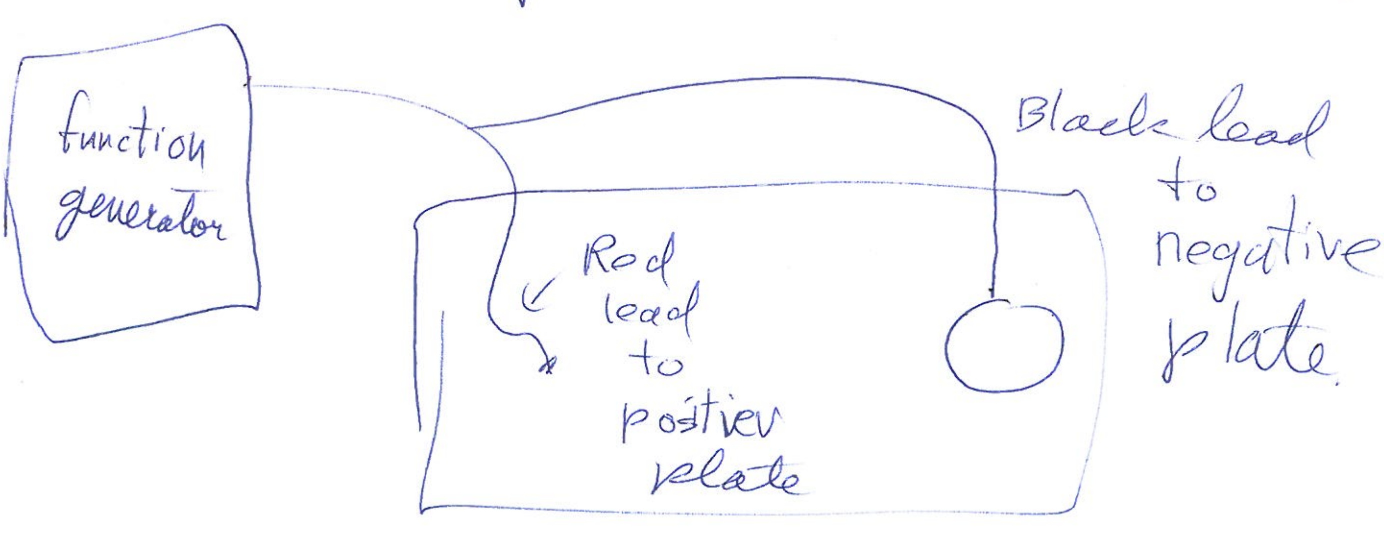
~~→ mark~~

— Trace on it two plate locations → so you know where to keep the plates — they are light and easily moved.





— one straight plate and one funny shaped (but not too large) plate works well.



(nothing safer than putting live wires in water)

The function generator provides an AC potential to the plates.

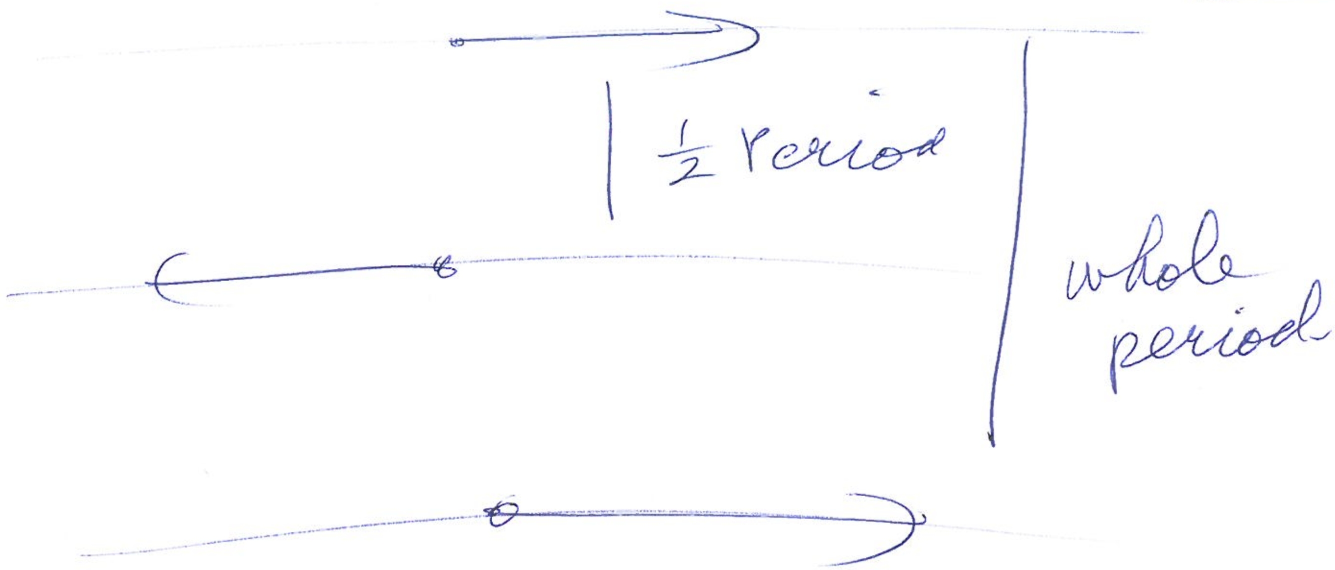
— They are nearly equipotentials at an instant in time

charge is moving in conductors, but resistance is low and so nearly equipotential in and on conductors.

34)

~~The plates create~~

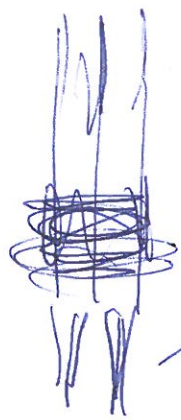
The charge in the plates creates an E-field which because the signal is AC is actually varying in time but the Root Mean Square (RMS) magnitude at every point is constant and direction is constant except for ~~sense~~ flips



So the field lines stay constant except for direction sense

We arbitrarily say the field lines run from the red connected plate to the black connected plate.

We use
a <u>multimeter</u>
to measure
ΔV
over a fixed Δs



prongs of multimeter
taped together.

The multimeter is set
to potential measurement
$\rightarrow$ AC

$\boxed{\text{Select}}$ ← push select
to get the "~" symbol

The multimeter Reads RMS potential difference (so no sign)

It autoscales and check the units: Volts or millivolts.

Question Why do we need the water

Answer to measure potential the multimeter must.....

Tap water has lots of ions in it.

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Question Why use AC?
Wouldn't DC work?

Answer Well AC
lets us use
the headsets
and hear
the AC.

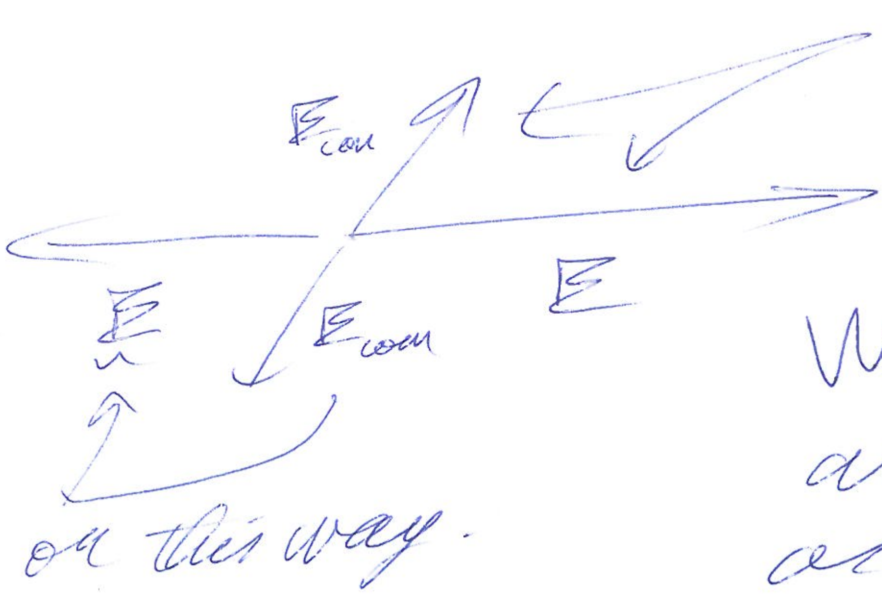
And well the
ions would
lead to

...

Because we use AC and ΔV is just the <u>RMS</u> value of a time varying field

$$\left| E_{com} \right| \cong \frac{\Delta V}{\Delta s}$$

We don't get the sign of the component.



We choose arbitrarily as stated above on p. 35

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Red positive
Black negative

traditional choice in electrica circuits

- so our choice of red and black connections decides the field direction.