# Capacitor Lab design

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## To-do Design

- ~~Design new bar meters that look like meters with clear min / max values~~
    - ~~Think about capacitance meter, dial 3-4x as expensive as bar meter, maybe a bar with a line indicator instead of filled in~~
    - ~~Add energy meter~~
    - ~~Add text values for meters~~
- Work out max values for V, C, and Q (for use in meters)
- Work out values of A, d, dielectric constant min and max.
- Decide on whether to have check boxes (and) or radio buttons (or) for field vectors in detector
- ~~Where does the charge slider (when disconnected) go? In front of dielectric? Somewhere else?~~
    - ~~Move charge slider above cap to get out of way of dielectric.~~
- ~~Where should disconnect button go? Bad use of space right now.~~

    - ~~Change "disconnect" to "remove wires" and "add wires", above top wire~~
- Model for how far apart charges are in dielectric, depends on E field?
    - Done - proportional to Q_excess -Noah Podolefsky 5/13/10 10:44 AM
    - Need to make + and - direction aligned when Q_excess = 0
- Think about field inside dielectric and maybe "see inside" button?
- Some sort of dashed lines or something to indicate detecting plane, 2D cross section.
- How to deal with range of charge in meter.
    - Maybe add a "x10" button, zoom?
    - Decided to try a user activated auto-zoom, described below.
- Consider "autoscale" button for bar meters.
    - Single button with magnifying glass, "Autoscale" text on mouse hover
    - Blink red max value text
    - Arrow above meter to indicate overload

# Notes 9/28/10

~~- should field detector be "field detector", or "E-field detector" or "Electric Field Detector"~~
~~- make plates and dielectric transparent when detector or volt meter is turned on (so you can see probe behind the plate or inside dielectric)~~
~~- make probe 3D so grabbable even when "tip" is behind something~~
~~- current indicator need to be sensitive to direction of moving battery slider, not +/- side of battery~~
~~- add labels to vectors in E-field meter~~
~~- maybe get rid of "From" on checkboxes, change header to say "Show Field From"~~
~~- mock up new design of multiple caps tab~~
- remove View, plate charge box, plate charge meter (think about field detector) from multiple caps tab
Want to keep charges shown in multiple capacitors tab -Noah Podolefsky 10/1/10 2:00 PM

# Design Overview and Learning Goals

*Learning Goals*

1. To determine the relationship between charge and voltage for a capacitor.
2. To determine the energy stored in a capacitor or a set of capacitors in a circuit.
3. To discuss the effect of space and dielectric materials inserted between the conductors of the capacitor in a circuit.
4. To determine the equivalent capacitance of a set of capacitors in series and in parallel in a circuit.

# Resources

- http://en.wikipedia.org/wiki/Capacitance
- http://hyperphysics.phy-astr.gsu.edu/hbase/electric/capac.html
- http://hyperphysics.phy-astr.gsu.edu/HBASE/electric/dielec.html

# Physical Model

## *Model was checked by Steve P, 5/11/10 -Noah Podolefsky 5/11/10 4:18 PM*

**Basic Capacitor Model**

- In this sim, we use a capacitor consisting of two parallel conducting plates. A capacitor stores charges on its plates.
- The capacitance, *C*, is based purely on the geometry:

  $$C = \epsilon_r \epsilon_0 \frac{A}{d}$$

  where $\epsilon_0 = 8.854 \times 10^{-12} F / m$, A is the area of each plate, and d is the distance between plates. $\epsilon_r$ is the relative permittivity (or dielectric constant, sometimes designated k) of the material between the plates. For air, $\epsilon_r = \epsilon_{air} \approx 1.00059$. (Other values of $\epsilon_r$ can be found here.)

- The capacitance can also be written $C = \frac{Q}{V}$, where *Q* is the charge on each plate (in Coulombs), *V* is the voltage between the plates (in volts), and *C* is measured in Farads (*F*).
  - For a given capacitance, this equation can be used to calculate voltage with *constant charge* ($V = \frac{Q}{C}$), or charge with *constant voltage* ($Q = CV$).
  - Constant *V* is achieved by connecting the capacitor to a battery (of voltage *V*).
  - Constant *Q* is achieved by charging the capacitor and then disconnecting from the battery (which isolates the capacitor).

**Electric Field**

- The electric field (E-field) from the capacitor plates is given by

  $$E = V / d$$

  where E is the magnitude of the electric field, d is the distance between the plates.

  - Note this is the field due to the plates only.
  - This will be also be the net field when there is vacuum between the plates.
  - Adding a dielectric material (including air) will change the net field, although the field just due to the plates will still be V / d.

- E-field between the plates is represented by either field lines (density of lines ~ magnitude of field) or vectors (length of vectors ~ magnitude of field).

**Dielectric**

- The dielectric increases the capacitance. It does so because the dielectric becomes polarized and creates a field opposing the field due to the charges on the plates. This allows the field from the plates to be larger, while keeping the net electric field the same, which therefore allows more charge to build up.
  - The effective field is given by

    $$E_{effective} = E_{plates} - E_{dielectric} = \frac{\sigma}{\epsilon_r \epsilon_0}$$

    where the surface charge density on the plates is $\sigma = \frac{Q}{A}$.

  - The field due to plates and dielectric can be separately calculated:

    $$E_{plates} = \frac{\sigma}{\epsilon_0}$$

    and

    $$E_{dielectric} = E_{plates} - E_{effective}.$$

  - The dielectric field points opposite to the plate field.
  - Can calculate dielectric charge from model above
    - The "excess" charge on the plate with a dielectric inserted is

      $$Q_{excess} = (\epsilon_r - 1)\epsilon_0 \frac{A_{dielectric}}{d} V$$

      where Adielectric is the area of the dielectric inserted between the plates. (Adielectric = A when fully inserted, = 0 when pulled completely out).

    - The charge on the dielectric is equal in magnitude to this excess charge. The sign of the dielectric charge is opposite to the adjacent plate charge.
    - Physical separation between + and - charges shown in dielectric is proportional to $Q_{excess}$

- If a dielectric is only partially inserted between the plates, the effect is proportional to the fraction inserted. You can calculate the resulting capacitance with:

$$C=\left(\frac{A_{dielectric}}{A}\epsilon_r+\frac{A-A_{dielectric}}{A}\epsilon_{air}\right)\frac{\epsilon_0 A}{d}=[A_{dielectric}\epsilon_r+(A-A_{dielectric})\epsilon_{air}]\frac{\epsilon_0}{d}$$

where $A_d$ is the area of the dielectric between the plates.

- The equation above gives the total capacitance, but to get correct values for the charge and field in different areas, this should be modeled as two capacitors in parallel.
  - One capacitor represents the plate area enclosing air. The other capacitor represents the plate area enclosing the dielectric (the part that is inserted).
  - Both "virtual" capacitors have the same voltage.
  - One capacitor ($C_a$) has a dielectric constant of air: $C_a=\epsilon_{air}\epsilon_0\frac{(A-A_{dielectric})}{d}$.
  - The other capciror ($C_d$) had the dielectric constant of the dielectric material: $C_d=\epsilon_r\epsilon_0\frac{A_{dielectric}}{d}$
  - When connected to a battery, the voltage on both virtual capacitors is the same and equal to the battery voltage.
  - When disconnected, the total charge on both capacitors is constant. The charge in each area of the plate, corresponding to each virtual cap, is given by $Q=CV$ (where $V$ is the same on each, $C_a$ and $C_d$ are given above).
  - All variables ($Q_{excess}$, E-fields, etc.) should be calculated separately for these two capacitors. Essentially, treat these like two separate capacitors that have been "stuck together".
  - The total capacitance is given as $C_{total}=C_a+C_d$ (see also parallel capacitors below)

- The surface charge, voltage, and E-field for the part of the dielectric *outside* of the plates are all zero. Basically, nothing is happening in the dielectric outside of the plates.

**Energy**

- Capacitors store energy in the electric field between the plates. The unit of energy is Joules (J).
- Energy is found by integrating the field over the volume between the plates.
- The result gives the energy, $U$, as:

$$U=\frac{1}{2}\epsilon_r\epsilon_0 AdE^2=\frac{1}{2}CV^2$$

where $E$ is the magnitude of the electric field between the plates. (Note that $Ad$ is the volume enclosed between the plates.)

**Series / Parallel Capacitors**

- Capacitors in *series* add according to $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + ...$, where $C_{eq}$ is the equivalent capacitance.
- Capacitors in *parallel* add according to $C_{eq} = C_1 + C_2 + ...$

Also will need model for which way charges should be shown to flow, but that should be easy. -Katherine Perkins 3/8/10 9:07 PM
"Should be" easy, but let's add it now to make sure it really is easy. -Chris Malley 4/13/10 9:16 AM
Added this in the "Current Indicator" section below -Noah Podolefsky 4/13/10 10:37 AM

**Force on Dielectric** (*short story - we can ignore this*)

- Note that a dielectric will fee a force trying to pull it into the capacitor. One way to think about this is that the energy stored is lower with the dielectric inserted, so it is trying to get to a lower energy. Another way is to realize that at the edges, the fringe field has a horizontal component. This acts on the charge in the dielectric, creating a force into the plates.
  - The force is given by

$$F_{dielecric} = \frac{1}{2}(\epsilon_r - 1)\epsilon_0 \frac{A}{d} V^2$$

  - Note that for constant *V* (attached to battery), the force is constant. When detached, force will vary as *V* changes.
  - However, this force is *tiny*. For a capacitor with *A* comparable to *d* (say *A=10d*), this means the force is about $10^{-11}V^2$. At 10 volts, this is a force of about $10^{-9}$ N. For a 10g block of teflon, this is an acceleration of $10^{-10}$ m/s$^2$.
  - **The point is, this force can be ignored for the capacitor geometry in this sim.**

**Model Summary**

Below is a summary of the user settings and all formulas.

**Constants**

| **Symbol** | **Definition** | **Units** | **Value** |
|---|---|---|---|
| epilon_0 | Permittivity of free space | Farads / meter | 8.854E-12 |
| epilon_air | Relative permitivity of air | Farads / meter | 1.0005896 |

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**User Settings**

| Symbol | Definition | Units | Min | Max | Notes |
|---|---|---|---|---|---|
| V_battery | Battery voltage | volts | 0.0 | 10.0 | Actually -10.0 to +10.0 |
| Q_disconnected | Total plate charge when battery disconnected | Coulombs | 0.0 | 7.0832E-11 | Max is 10V * maximum capacitance |
| L | Plate side length | meters | 0.010 | 0.020 | |
| d | Plate separation | meters | 0.005 | 0.010 | |
| offset | How far dielectric is pulled out | meters | 0.000 | 0.020 | 0.0 is completely in |
| epsilon_r | dielectric constant of the dielectric | dimensionless | 1.000 | 10.000 | 1.0 i vacuum |

**Derived**

I've tried to make sure that each variable can be calculated from the variables above it (to try and avoid any circular formula). This should be double checked.

Note that in some cases the separation, *d*, appears in the denominator. We avoid divide by zero errors by limiting *d* so that it can never be zero in the sim.

| Symbol | Definition | Units | Formula |
|---|---|---|---|
| A | Plate area | meters^2 | L * L |
| A_dielectric | Area of dielectric between plates | meters^2 | L * (L - offset) |
| C_air | capacitance of air capacitor | Farads | epsilon_air * epsilon_0 * (A - A_dielectric) / d |
| C_dielectric | capacitance of dielectric capacitor | Farads | eisilon_r * epsilon_0 * (A_dielectric) / d |
| C_total | total capacitance | Farads | C_air + C_dielectric |
| V_plates | Voltage difference between plates | Volts | V_battery (when battery connected)<br><br>Q_disconnected / C_total (when battery disconnected) |
| Q_air | Plate charge for air cap area | Coulombs | C_air * V_plates |
| Q_dielectric | Plate charge for dielectric cap area | Coulombs | C_dielectric * V_plates |
| Q_total | Total charge on plate (top) | Coulombs | Q_air + Q_dielectric |
| Q_excess_air | Excess charge for air cap area | Coulombs | [(epsilon_air - 1) / epsilon_air] * C_air * V_plates |

| | | | |
|---|---|---|---|
| Q_excess_dielectric | Excess charge for dielectric cap area | Coulombs | [(epsilon_dielectric - 1) / epsilon_dielectric] * C_dielectric * V_plates |
| sigma_air | surface charge density for air cap | Coulombs / meter^2 | epsilon_air * epsilon_0 * V_plates / d |
| sigma_dielectric | surface charge density for dielectric cap | Coulombs / meter^2 | epsilon_r * epsilon_0 * V_plates / d |
| E_effective | effective (net) field between plates **(uniform everywhere between the plates)** | Volts / meter | V_plates / d |
| E_plates_air | field due to plate in the "air area" (A - A_dielecric) | Volts / meter | epsilon_air * V_plates / d |
| E_plates_dielectric | field due to the plate in the "dielectric area" (A_dielectric) | Volts / meter | epsilon_dielectric * V_plates / d |
| E_air | field due to air dielectric polarization (counters E_plates_air) | Volts / meter | E_plates_air - E_effective |
| E_dielectric | field due to dielectric polarization (counters E_plates_dielectric) | Volts / meter | E_plates_dielectric - E_effective |
| U | stored energy | Joules | 0.5 * C_total * V_plates^2 |

# Sim Layout

## Tab 1 - Introduction

### *Starting State*

- Battery at 0V
    - battery works like one in Faraday - can go from -10 to +10V, so switches directions going from + to -
- Capacitor has zero charge initially, battery is at zero volts
- Plates should have gradient as shown to look "metallic"
- Check boxes for:
    - View box
        - Plate charges (**default on**)
        - Field lines (default off)
    - Meters box (all default off)
        - Capacitance graph
        - Plate charge graph
        - Energy graph
        - Voltmeter
        - Field detector
- Can change capacitance by varying *plate area (A)* and *separation (d)*
    - Grabbing the vertical green arrow allows user to change plate separation

        - Plates stay equidistant from a center point - grabbing arrow and moving causes both plates to move together or apart.
        - Hovering over arrow should turn mouse pointer to hand
        - Can enter text in box, text also changes when you move arrow
    - Grabbing the diagonal arrow allows user to change plate area
        - The plates should keep the same aspect ratio as the area is changed (so they still look like they are square(ish) as area is changed)
        - Hovering over arrow should turn mouse pointer to hand
        - Can enter text in box, text also changes when you move arrow
- *Note plate area and separation values below are arbitrary - need to decide on best default values*
- KP: I would like to see Capacitance read out in a visual bar graph as well as a number value. I think by seeing the
  capacitance visually increase/decrease in a bar graph like state as you change things will really help make
  connections between plate area/diameter and capacitance. Possibly same with read-out on charge. Essentially, only
  way to change C is with Area/separation, but charge depends on C as well as depending on V. (Unsure if vertical or
  horizontal bar graph readout is better)
  Added bar graphs for capacitance and charge...see below -Noah Podolefsky 4/12/10 11:58 AM

These are not bar graphs, we not comparing anything. They are bar meters. -Chris Malley 4/12/10 12:29 PM

Actually, it is a bargraph meter. If you are comparing things, then it is a bar chart. : ) -Noah Podolefsky 4/13/10 9:57 AM

OK, I'm just wondering about the usefulness of a bar that has no scale, it's basically just some eye-candy that gets taller and shorter. And what is the range of these quantities, and can that range be effectively presented in the space provided on a linear scale? Or if a log scale is need, how will users know that it's log? -Chris Malley 4/13/10 9:00 AM

This was Kathy's suggestion, so she may want to weigh in. My thought is that we want something other than a text readout. It doesn't have to be a bar, but something that indicates "bigger is more". We've used bars for lots of things like this before, so I think it is appropriate...but I agree we need to think about the scale. -Noah Podolefsky 4/13/10 10:16 AM

I'd prefer to see something that looks like a meter; a hollow bar that gets filled in, so that user's can clearly see the max that we're able to display, and how the current value relates to that max.. -Chris Malley 4/13/10 9:17 AM

Good idea - I'll mock something up that looks more like a meter. -Noah Podolefsky 4/13/10 10:20 AM

New meter prototypes (below) -Noah Podolefsky 4/14/10 10:53 AM

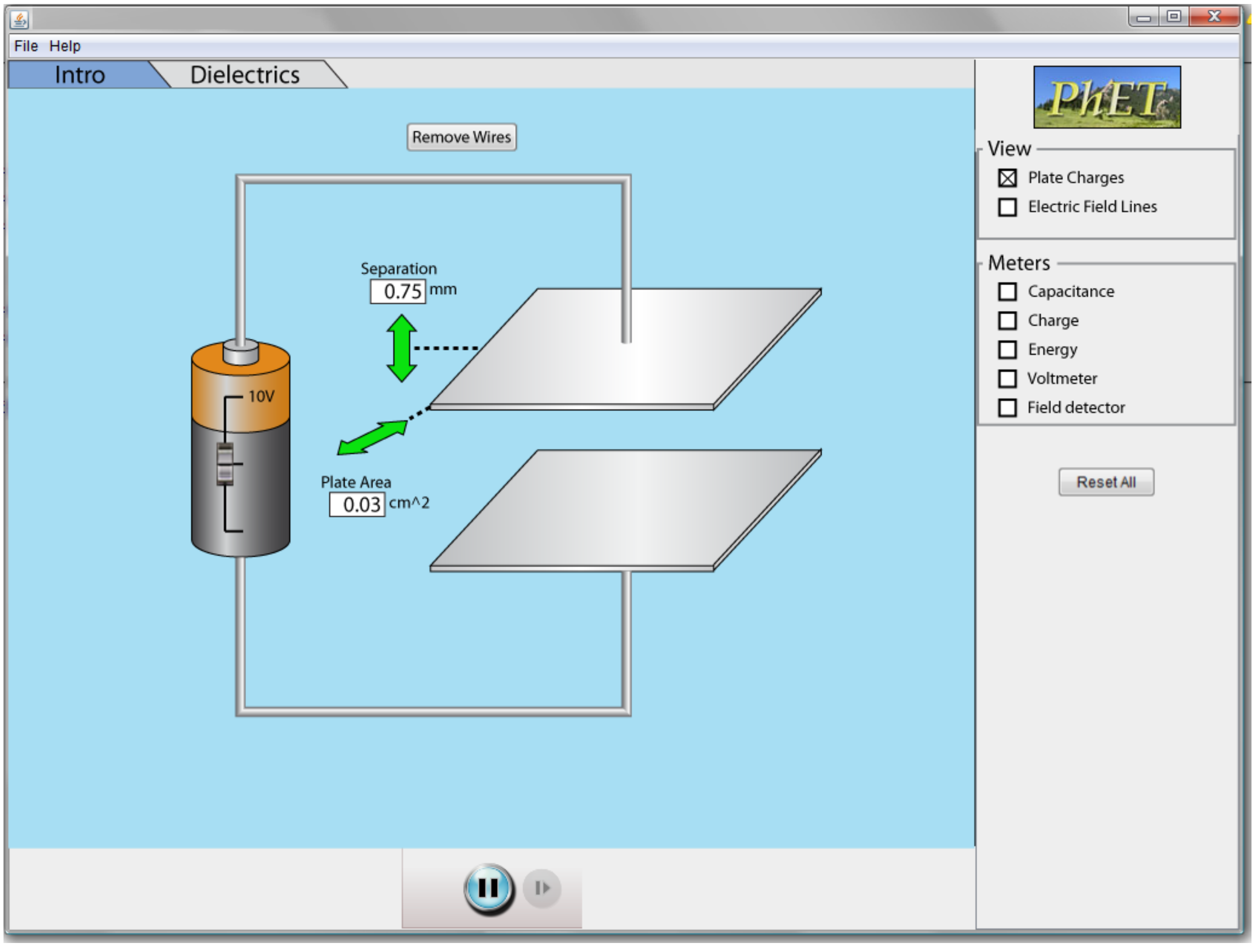
I like the new meters. Might be nice to also display the actual value. -Chris Malley 4/14/10 6:29 PM

- KP: Plates here are cream … seems like they should look like "metal" … so some shade of grey.

I agree metal look would be better - changed in the images below. I was using this color to match the caps in CCK. -Noah Podolefsky 4/8/10 2:05 PM
How about using an actual metal texture map, instead of a solid color? -Chris Malley 4/13/10 9:04 AM
That would be great, as long as it fits aesthetically with the rest of the sim appearance -Noah Podolefsky 4/13/10 10:18 AM Texture maps turned out to be problematic because of the 3D perspective. -Chris Malley 9/21/10 8:50 AM

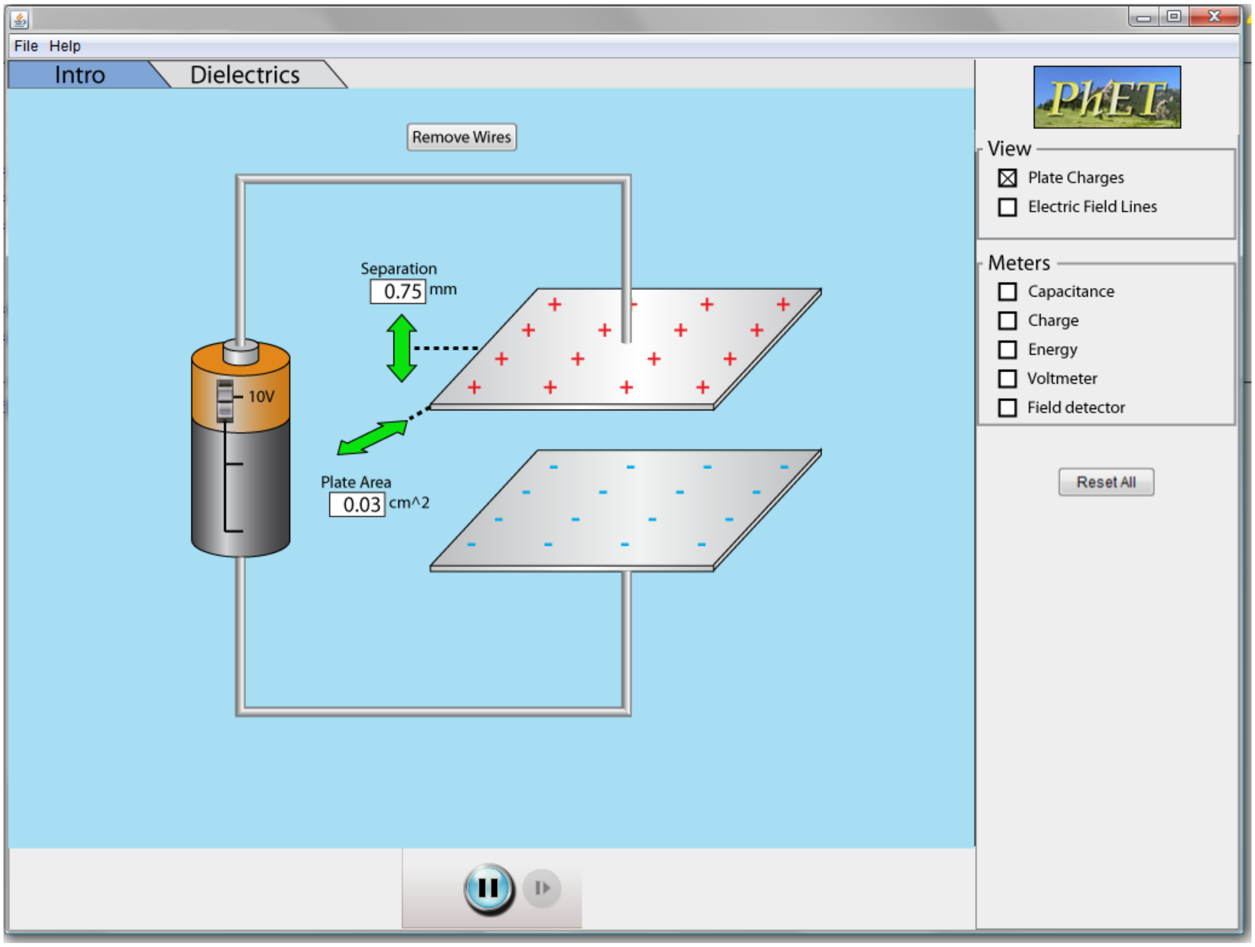
KP: Discussion of having handle on capacitor - but thought that was maybe not needed.
Also thought about using a handle - I think I'd like to see if this is needed in interviews first...but will keep this idea in mind. -Noah Podolefsky 4/8/10 2:05 PM
Which property would this handle control? Plate spacing? Area? -Chris Malley 4/13/10 9:04 AM
I'm not sure - this was Kathy's idea. -Noah Podolefsky 4/13/10 10:19 AM
Looked back at the notes and saw that there was a handle on the dielectric, but not capacitor plates. -Noah Podolefsky 4/14/10 10:46 AM

- **New 3D design below**. Have not decided between "face on" view (as below) or "side view" (previous look) for capacitor plates. Try to make this adjustable so we can see difference in action. -Noah Podolefsky 4/18/10 12:09 PM
- Decided on "side" view after much deliberation -Noah Podolefsky 4/29/10 4:09 PM




*Charged State*

- Changing battery voltage charges the capacitor
- Charges on plates represented by red +'s and blue -'s
    - number of + / -'s shown proportional to net charge on plates
- Started to implement this today and ran into the "orders of magnitude" issues. The smallest non-zero value you can set with the controls is around 1E-16. The largest is 1E-10. So we have 6 orders of magnitude to represent. And I can maybe fit 100 charges on each plate. How is this representation going to work for this range? -Chris Malley 9/27/10 5:59 PM




*Current Indicator while moving battery voltage slider*

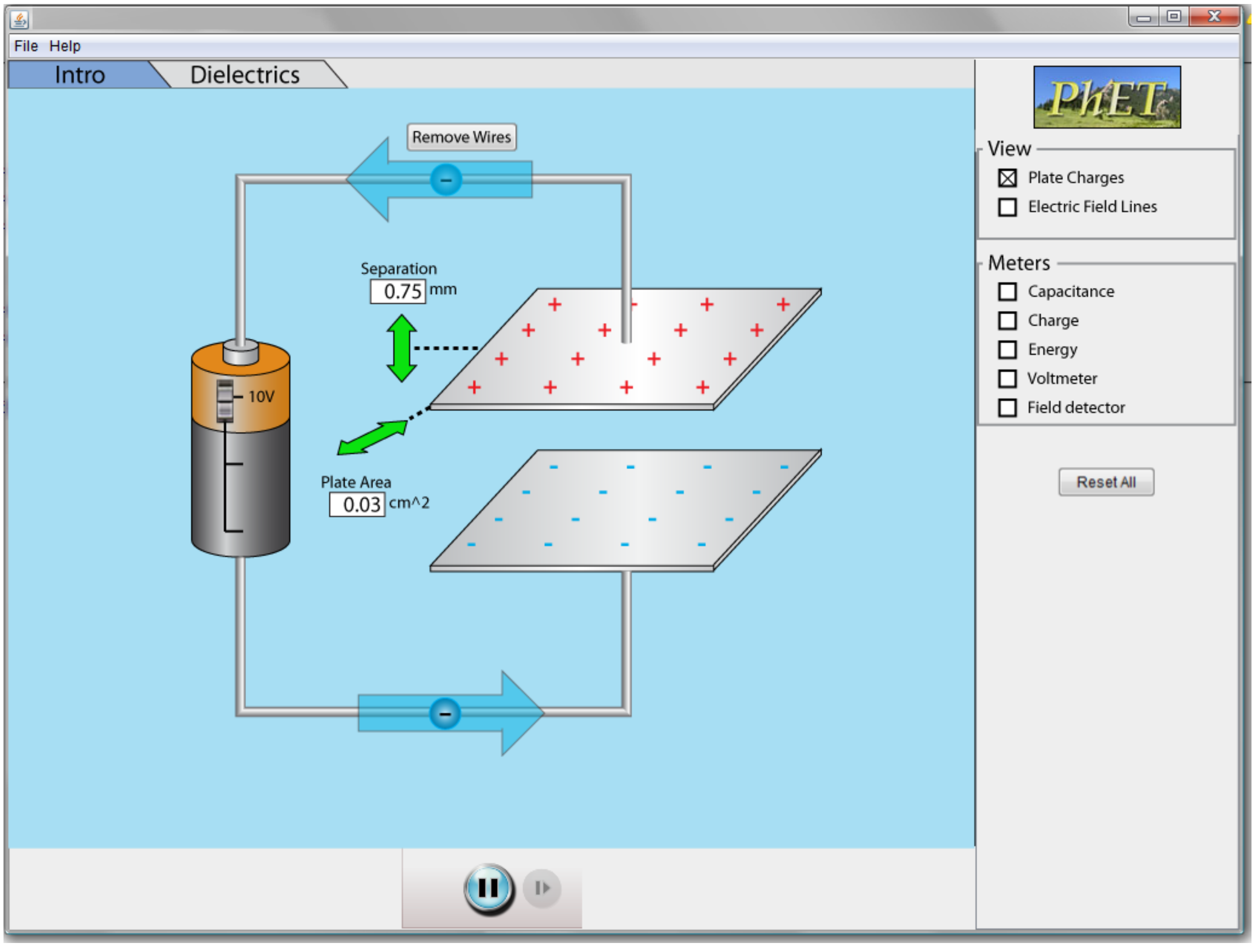
- Blue arrows / spheres should "glow" while V is *changing*, and then fade away when V is not changing (slider released or not moving)
- ~~Brightness of arrow and blue sphere should be proportional to dV/dt (optional)~~
  - This didn't actually look so good, so just constant transparency when current is flowing. -Noah Podolefsky 9/29/10 9:30 AM
- Should fade out in pretty short time when turning off (about 0.5 sec)
- This represents the flow of *negative* charge to / from the plates as the voltage is changed
- When battery voltage is *increasing* (becoming more positive), current flows *counter-clockwise*. When battery voltage is *decreasing* (more negative), current flows *clockwise*. Note that this is going to look odd to users - moving the slider up will make electrons flow down into the battery, and vice-versa. This is because of the physicist convention that charge carriers are negative. -Noah Podolefsky 4/13/10 10:36 AM

KP: I like this simplicity … and hope it works in interviews.

*Note - need to keep open the option of representing current as blue spheres flowing through wires, in case someone*

*decides this is what we want instead.* -Noah Podolefsky 4/12/10 1:01 PM
Wire would probably need to be thicker to accommodate blue spheres. -Chris Malley 4/13/10 9:05 AM
Agreed - thicker wire and / or smaller spheres *if* we use the moving spheres representation -Noah Podolefsky 4/13/10 10:26 AM

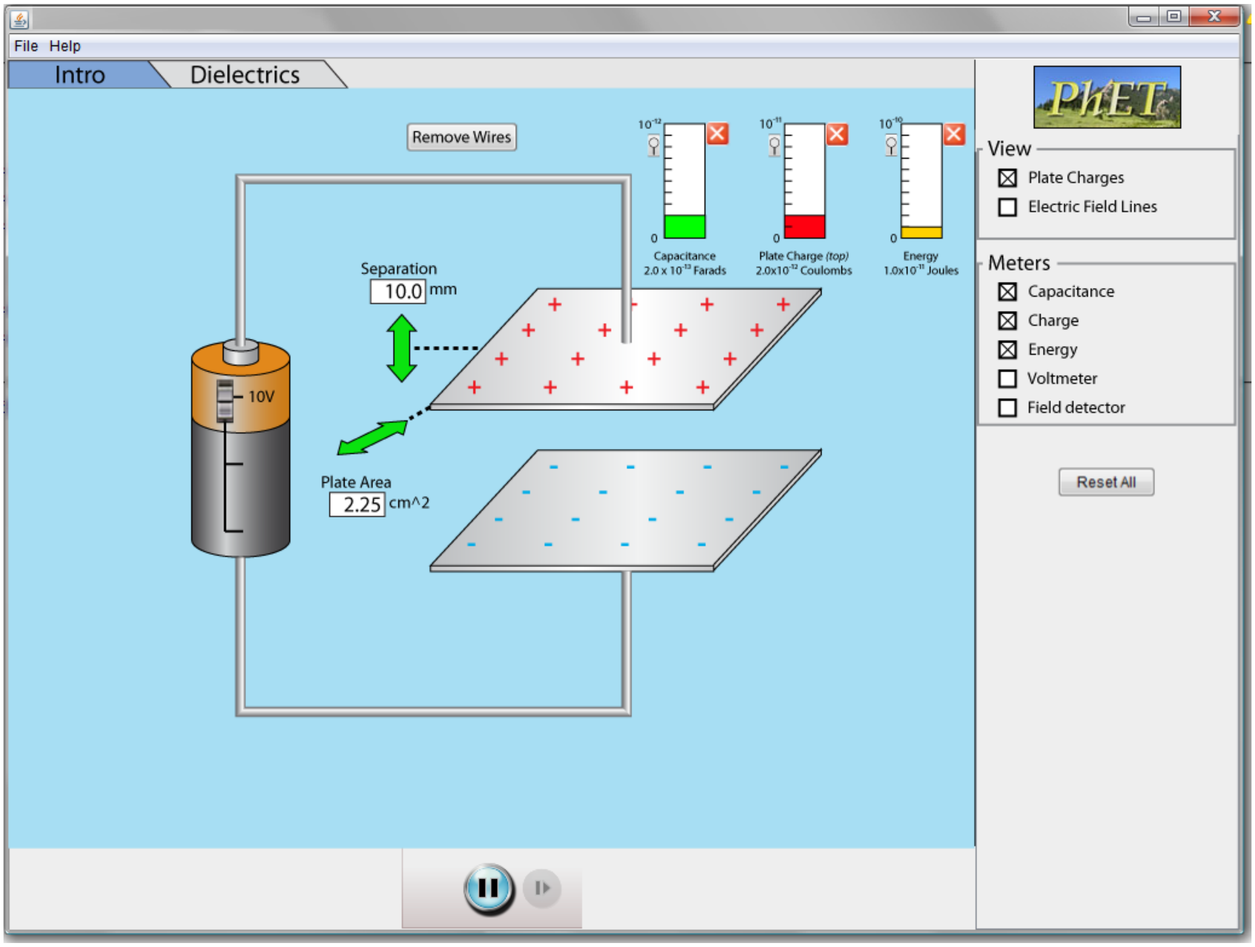
Does current ALWAYS show? Or do we need an option to turn it off? (I'm thinking probably not, but just want other opinions?) -Katherine Perkins 8/27/10 4:50 PM
I think current should always flow - doesn't seem very distracting in the sim -Noah Podolefsky 9/29/10 9:30 AM




## *Meters*

- Meters selected for capacitance, charge, and energy via check boxes
- Plate charge meter is red fill when top plate is positive, blue fill when top plate is negative
- Meters can be moved around play area
- Red X close buttons on each meter, so can turn off with button or unchecking box
- Meters have zoom buttons on left side (with magnifying glass icon)
    - Clicking the button causes the meter to auto-zoom
    - Zoom happens instantly

        - We discussed animating the zoom, but thought this might make users think the value was changing rather than the scale -Noah Podolefsky 6/9/10 11:16 AM
    - Max value label on meter flashes red several times to draw user's attention to the changing value
    - Auto-zoom determines the best scale for viewing the present value
        - Take the order of magnitude of the value (power of ten, e.g. $10^{-13}$)
        - Set max value of meter to 10* this value
        - E.g., if value is $2.0 \times 10^{-13}$, set max value to $10^{-12}$. If value is changed to $4.0 \times 10^{-12}$, clicking zoom will set max value to $10^{-11}$.
- Text below meters shows value using scientific notation (e.g., $2.0 \times 10^{-13}$ Farads)
- Capacitance uses a bar meter with just a line to indicate reading
    - Reads from 0 to $10^{-12}$ Farads by default
    - Note that $10^{-12}$ Farads is 1.0 *pico*-Farad. It is common to use prefixes like *pico (p)* and *micro (μ)* for capacitor values. Note sure what is the best notation style for this sim. -Noah Podolefsky 5/19/10 1:54 PM
- Charge uses bar meter
    - Reads from 0 to $10^{-11}$ Coulombs by default
- Energy uses bar meter
    - Reads from 0 to $10^{-10}$ Joules by default




*Field lines selected*

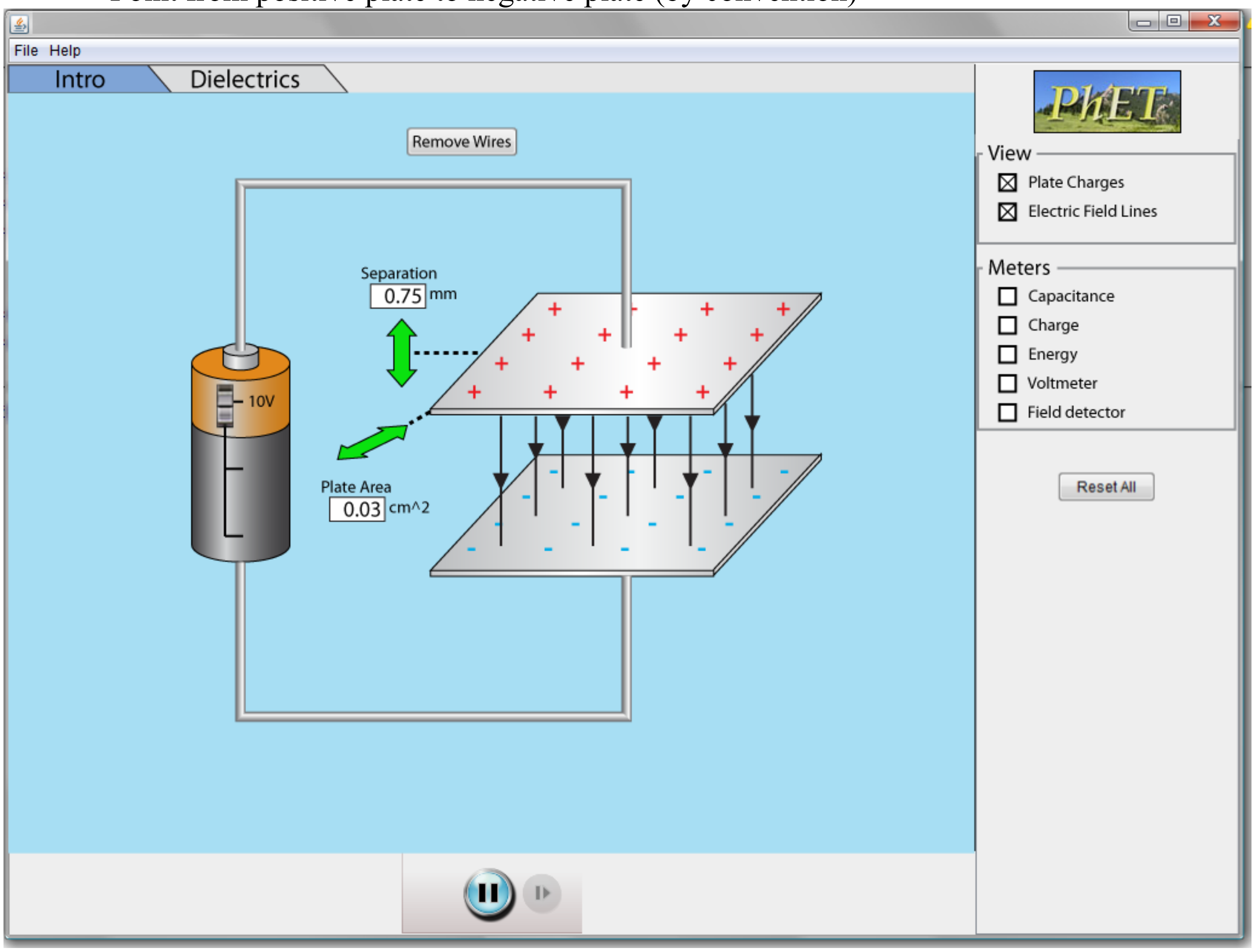
- Density of field lines proportional to net field strength (E_effective)
- Note that for a given E_effective, the field line spacing needs to remain constant.
- Will only show straight / vertical field lines - no "fringe field". (Curved field lines look too messy, and have other implementation problems. Decision confirmed by NP, CM, and KP on 10/5/10).

How many orders of magnitude difference is there between the min and max field strength? I want to make sure this is a usable representation for the full range of values. -Chris Malley 3/31/10 9:12 PM

Good question - E goes from zero to possibly huge, since ~1/separation. Will probably need to limit minimum separation, and this will limit maximum E. If max V = 10, and min separation is, say, 0.001 m, then this is factor of 1000. That is probably hard to show. Can make this factor of 100 by either making V_max = 1.0, or d_min = 0.01 m. I'd be in favor of limiting V, since separation of 1 mm is still pretty large for typical real capacitor -Noah Podolefsky 4/1/10 8:44 AM

OK, so how much would V need to be limited in order to make this work? And is that limited range acceptable to everyone? -Chris Malley 4/13/10 9:06 AM
I'll need to work this out...stay tuned. -Noah Podolefsky 4/13/10 10:38 AM
Started working on this today, there is indeed an "order of magnitude" issues here. Max for E_effective is 2E3, so we have 3 orders of magnitude to represent. How is this representation going to work?... -Chris Malley 9/27/10 6:09 PM

- Point from positive plate to negative plate (by convention)




*Battery Disconnected*

- When user clicks "Disconnect", wires disappear and button changes to "Connect"
- Cap is now isolated
  - So *fixed charge*, but now voltage can change when area and separation are varied
  - Changing battery voltage does nothing to cap

- If battery voltage is changed, then user clicks "Connect", current will then flow until the cap has changed to the new voltage

KP: I was thinking that we discussed that when battery was disconnected you would now be able to change the Charge on the plate directly? So when battery was connected “charge” would be a readout, and when battery was disconnected, a “slider control” would be added to the “charge” readout that let you adjust it. I know Chris isn’t going to care for this dual role, but lets discuss. I just think if you want to be able to change the charge and see the difference it is going to be a pain to keep attaching the battery to do so. I think this dual ability with charge, might warrant use of a charge “bar graph” type readout.

I added a slider to adjust the plate charge manually when the battery is disconnected. Open to feedback on this. -Noah Podolefsky 4/8/10 2:54 PM

If it's a slider that just changes from read-only to editable, I'm OK with this. If it's a control that looks totally different depending on whether the battery is connected, then Kathy is correct, I don't like type here -Chris Malley 4/12/10 12:23 PM  it. -Chris Malley 4/12/10 12:20 PM

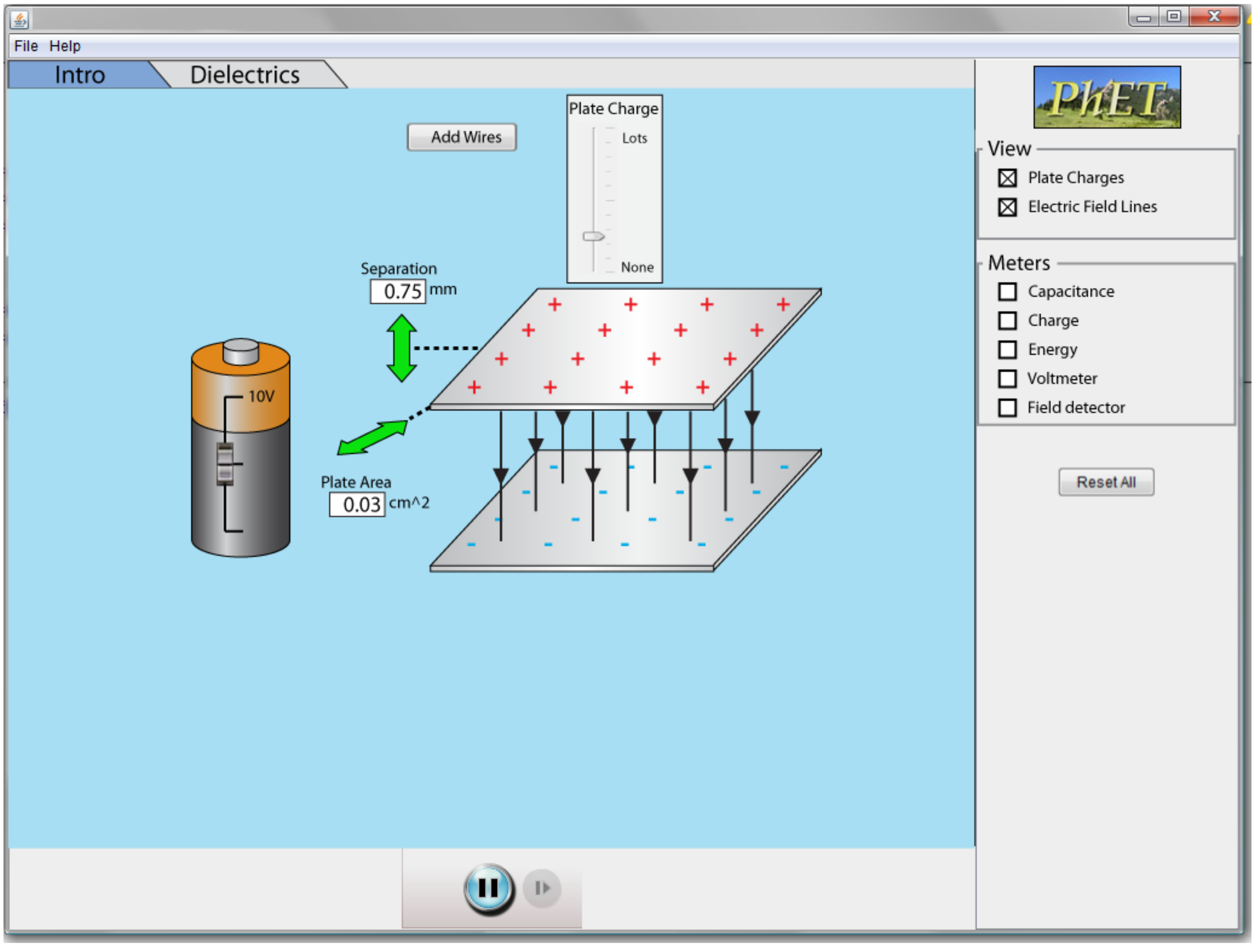
It is a control that only appears when the battery is disconnected. -Noah Podolefsky 4/13/10 9:59 AM

That's not what Kathy's proposal says above, it's a display when the battery is connected, a control when the battery is disconnected. -Chris Malley 4/13/10 9:08 AM

I thought it would be better to keep the charge readout (bar), but just add the slider when batter disconnected. I didn't like having the readout change to a control. The bar would track the control, so sort of redundant, so let me know if this seems like poor design to you. -Noah Podolefsky 4/13/10 10:31 AM

What about moving the add/remove wires button to just below the bottom wire - so it makes the top part less crowded? -Katherine Perkins 8/27/10 5:04 PM

I tried KP's suggestion.  But moving the Add/Remove Wires button to below the bottom wire moves it far away from the Plate Charge control that appears when you press "Remove Wires".  So I don't think we should move the button without relocating the Plate Charge control.  And if we move the Plate Charge control, then it will be conflict with the default location of the Voltmeter and Field Meter. -Chris Malley 9/23/10 2:11 PM




*Volt meter*

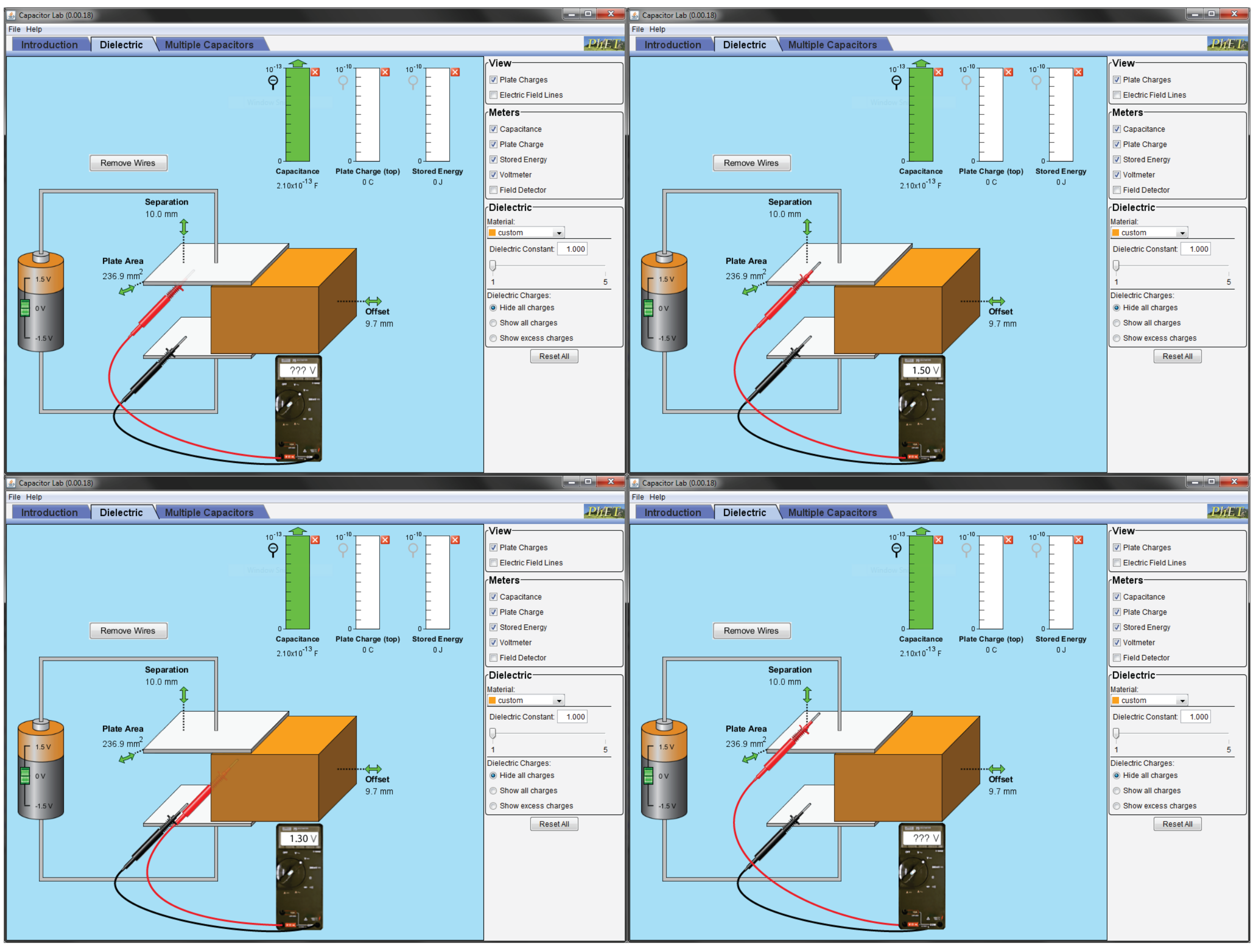
- Voltmeter similar to one used in CCK\
- Can move the meter and the leads to measure voltage difference
- The probes should be rotated to match the perspective of the plates. This way the "tips" appear to be in the plane of the wires, with the "handle" part of the probe sticking out of the screen.
  - Top left image shows red probe below top plate.
  - Top right image shows red probe on top plate.
  - Bottom right image shows red probe above top plate.
  - Bottom left image shows red probe in dielectric.

- In order to cue users of where the probes are located in 3D, use the following algorithm:
  - Plates and dielectric are transparent, so that when probe is "behind" a plate you see it through the plate. The voltmeter will read "???".
  - When the probe is in the center of a plate, it is in a layer in front of the plate (fully visible). The voltmeter will give a reading.

- When the probe is in the dielectric, the probe appears behind the front face of the dielectric. The voltmeter gives a reading, which is proportional to the distance across the dielectric.
- Probe is always in front of the battery; voltmeter reads "???"
- Probe is always in front of wires; gives a reading when on a wire.

Will have to discuss this - need to come up with simple model for how to determine voltage depending on where it is measured -Noah Podolefsky 4/1/10 2:15 PM

Voltmeter has similar usability issues to the Field Detector (see below for list of issues). The main problem is knowing where the probes are located in 3D space, and interaction in 3D space with other objects (plates, dielectric and wires.) -Chris Malley 9/27/10 11:31 AM



*Field detector*

- Field meter shows the field direction and strength in the plane of the wires
  - Detector "probe" and meter body are both moveable
  - Probe behaves like the voltmeter probes (being seen in front of / behind plates)
  - Vector magnitude is proportional to E_effective
- Close by unchecking or using close button in detector
- Shows the field as a vector
- Field is constant "inside" the capacitor; field is zero outside
  - Should have some "fringe" field just outside of capacitor, drops off quickly with distance from edge

KP: I think Mike said we could "program in a fringe field" so won't just be absolutely 0 outside, it will drop off.

Mike - can you provide a model for the fringe field? -Noah Podolefsky 4/8/10 3:22 PM

- Can also click a box to "Show Value", which displays text values for vectors

Need to figure out where these will fit -Noah Podolefsky 4/8/10 3:23 PM

KP: I recommend renaming this "Field Detector". This would be main way of viewing the vector representation. The "readout" box is larger than shown, would be movable, and would have an E-field vector display section that would show the vectors. Within the readout box, you would be able to select "From Plate", "From dielectric" or "Sum of fields" (color coded to match label).. If you were on first tab … it would not have these options because we would only be talking about the plate. It could have a checkbox to say "show values". Vectors would grow and shrink as you change all of controls – battery, capacitor size, separation, etc. You might need a zoom in/out on the vector display to keep in on scale. The readout box itself would be movable so that you can place it where ever you find convenient.

See new design below -Noah Podolefsky 4/8/10 3:25 PM

Kathy's specification of the 3 choices was "or". The design uses check boxes, which is "and". Which is correct? When "Show values" is selected, where do the values appear, what units, how many decimal places, etc? -Chris Malley 4/12/10 12:19 PM

I interpreted "or" pretty loosely - I thought it would be useful to see all vectors at once so that users could see how the plate and dielectric fields add to the sum -Noah Podolefsky 4/13/10 10:45 AM

Sorry, but or/and are not something that can be loosely programmed ;-) Chris Malley 4/14/10 6:20 PM

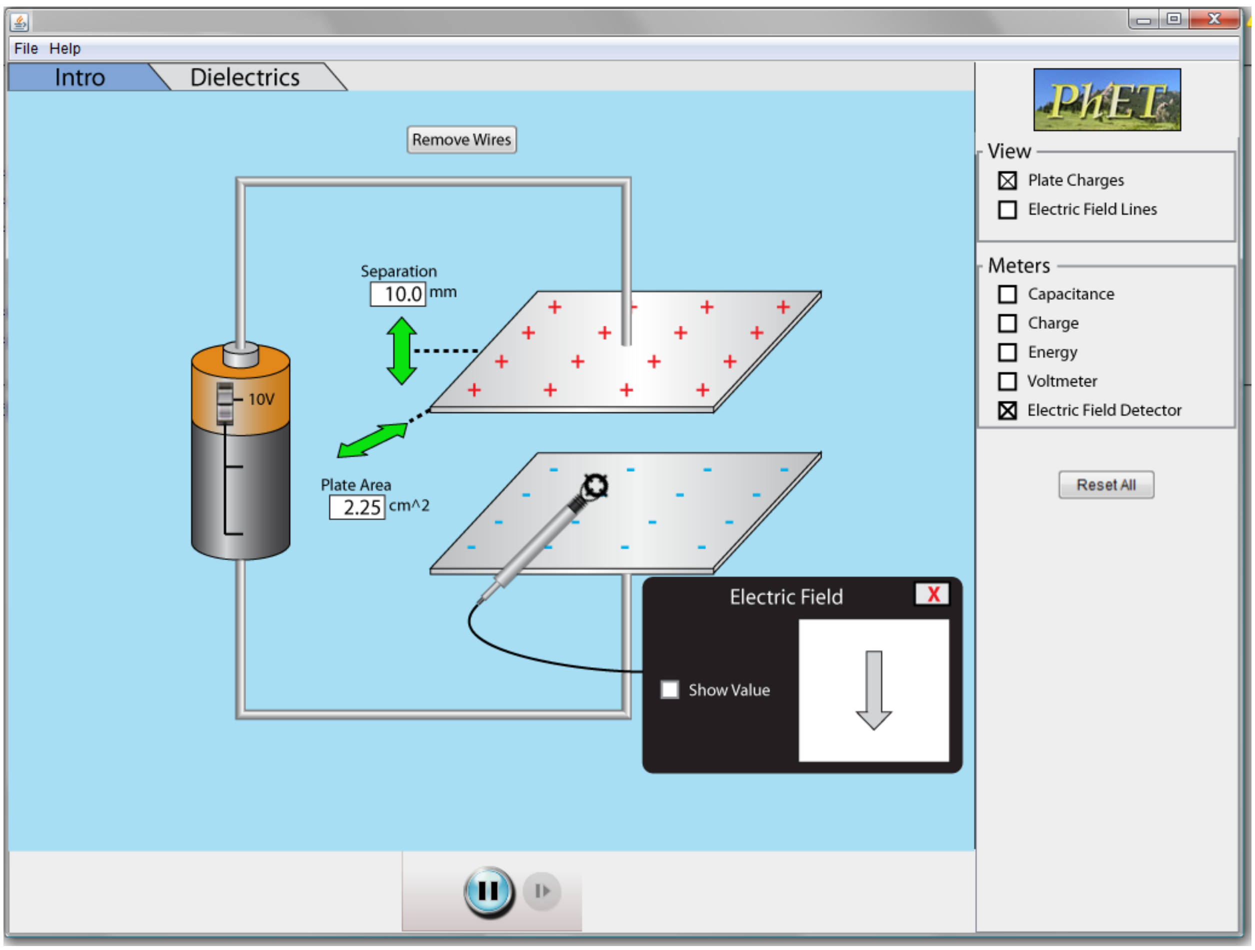
Lots of user interface issues with this Field Detector.

(1) It's not obvious where the probe is in 3D space. (It's probably the same 2D plane as the wires.)

(2) How does the probe interact with plates? Does it get obscured by the plates? Can it pass

through a plate? etc.
(3) How does the probe interact with the dielectric? Can it get behind the left side of the dielectric? Can it pass through the dielectric? etc.
(4) If the probe is released when behind something, the user will lose access to it. How to handle this?
Discussed all of these with Noah on 9/27/10.
-Chris Malley 9/27/10 11:26 AM

Another problem with the Field Detector... It shows the field as a vector. But the range of the field varies by 3 orders of magnitude. That's going to be difficult to map onto a graphical arrow that's less than 100 pixels long. -Chris Malley 9/27/10 6:14 PM




## Tab 2 - Dielectrics

KP: I'd like to discuss representation for dielectric charges that is in optical tweezers and see what folks think about

that in comparison to showing this dipole representation. I'm also wondering which is more physically accurate
visualization?

I changed the design to incorporate Optical Tweezers representation - I like the way this looks, as long as it is not too busy -Noah Podolefsky 4/12/10 12:59 PM

*Dielectric - Initial State*

- Starts with dielectric off to the side - other elements need to be moved to left of play area to make room

How will the user know that this box is the dielectrtic? -Chris Malley 4/5/10 2:10 PM

Added a label to the dielectric in image below (note that this won't work in the "dipole" representation, but not sure I like this rep anyway-Noah Podolefsky 4/6/10 9:30 AM

- Add "Dielectric" slider to control panel
    - Right now there is no representation of what the constant is other than the slider - probably OK, but could imagine changing dielectric color to represent constant. Maybe the darkness? Or transparency? A dielectric constant of 1 is essentially air, so having dielectric totally transparent would kind of make sense in this case.

KP: I like idea of having another cue. I'm wondering about interpretation
of darkness – might be interpreted as "more material" which isn't really
the case. But might work.
o KP: Capacitor should "look" like a plastic … so maybe a cream.

Dielectrics are commonly paper, mica, ceramic, oil or some sort of electrolyte. Plastics do have dielectric qualities, but not sure they are commonly used in real capacitors. I made this on a cream color, which is pretty generic, but not sure this is really very accurate consider the materials that are actually used. -Noah Podolefsky 4/8/10 3:33 PM

- Add check boxes to show field from plate, dielectric, and the sum (net field)
    - Not sure if check boxes are the best - would be nice to be able to show these at the same time to compare, but could also get cluttered especially with field lines

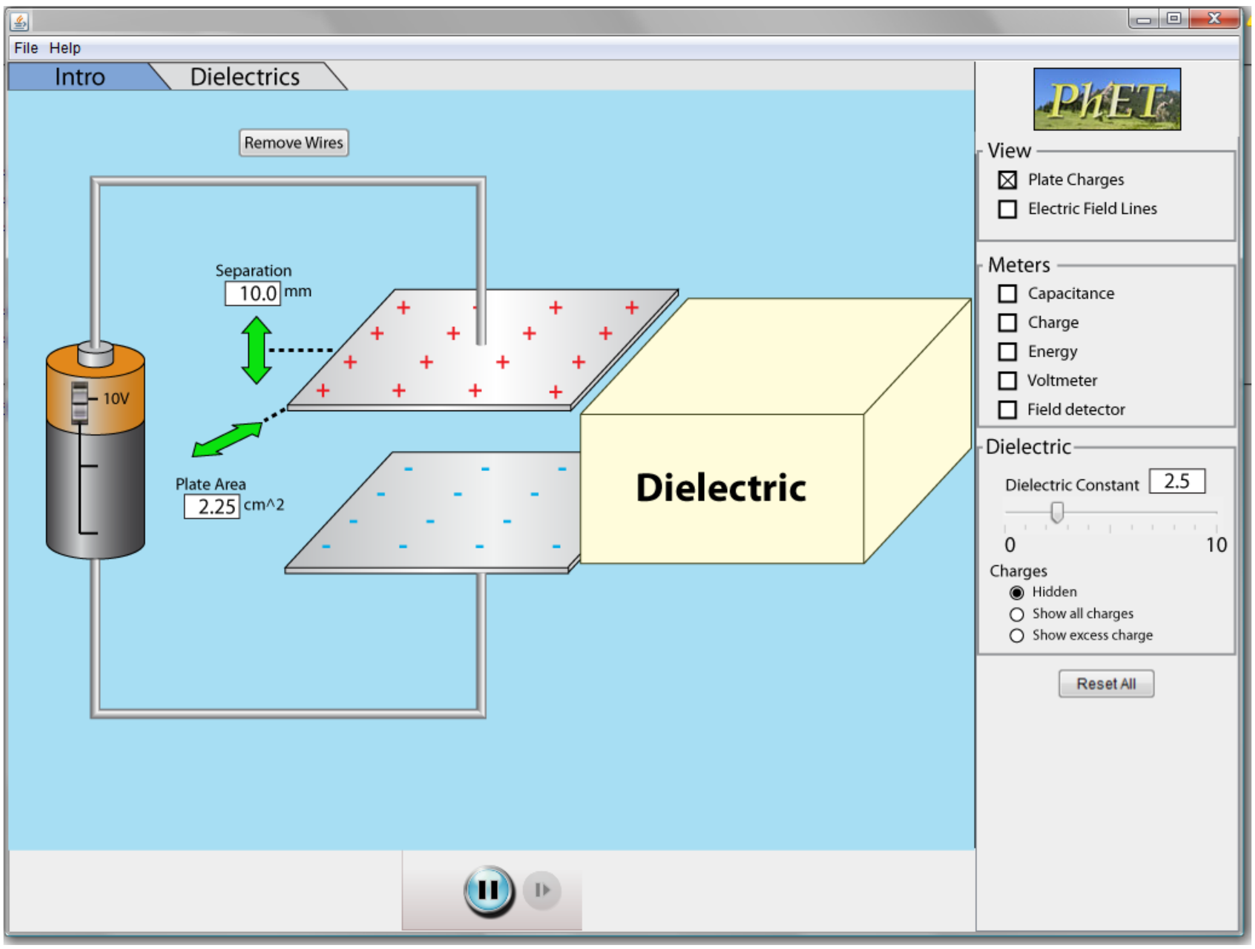
KP: I was thinking that contribution of each to the field would only be viewable with the vectors in the "field meter" That the field lines would be only the net e-field? I guess I think of "vector addition" but I don't really think of field like representation when I'm thinking about superposition of fields. Might just be me, how do other folks think about this?

I agree with KP. I changed to vectors are only in field detector -Noah Podolefsky 4/12/10 12:03 PM

- Dielectric can be grabbed and slid into capacitor (can only be moved left / right)
    - Can be moved partially between cap plates - see model above for behavior when only partially inserted
    - Cursor should change to left / right double arrow over dielectric.

◦ Dielectric is always sized to fit the capacitor plates. That is, it's top and bottom are the same size / shape as the plates, and thickness is same as plate separation. (*Note that the image below shows a gap between the dielectric and plate - there should NOT be a gap. This change was made 10/21/10 by NP).*

I think users will figure this out without need for a "position" slider. It is a big thing that just appeared, have to see in interviews, but I think intuitive to grab it and move to left. -Noah Podolefsky 4/12/10 12:04 PM
Inconsistent to have controls + direct manipulation for all other properties except this one. If you want to be consistent, add a slider named "Position" whose range is "inside" to "outside". -Chris Malley 4/13/10 9:10 AM
Would it be consistent to have only sliders for capacitor, but only direct manipulation for the dielectric? Could add a handle to the dielectric to cue users to grab it. -Noah Podolefsky 4/14/10 10:56 AM



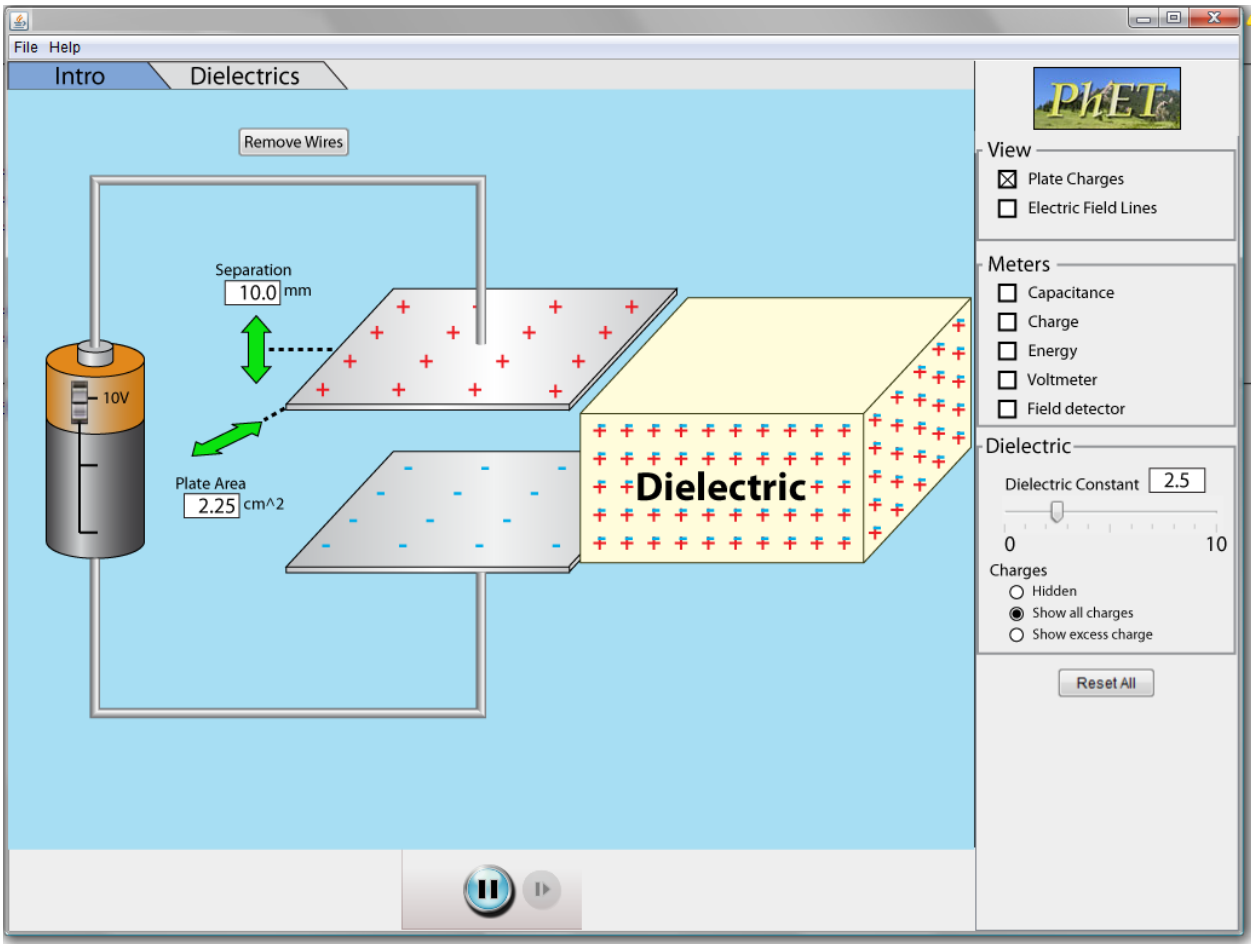

*All charges shown*

- When outside of cap, charges are paired together and not separated
- Charges will separate when dielectric is inserted, as shown below
- Number of +/- pairs is constant, each pair represents "an atom"
- Only the spacing between + and -'s changes; density of +/- pairs is constant (constant spacing)

- Separation between + and - in each pair is proportional to *E_dielectric* (or *Q_excess_dielectric / A_dielectric*, both are the same up to a constant multiplier)

Need to decide if we want to use "induced dipole" representation, as shown below, or "permanent dipole" representation, where the dipoles rotate rather than separate. Both are used, depending on the dielectric material. I think it is somewhat easier to understand how you get an excess charge from the induced dipoles, and easier transition from "all charges" to "excess charge" this way. -Noah Podolefsky 4/14/10 10:59 AM

I started implementing this today and immediately ran into "orders of magnitude" issues. The smallest non-zero Q_excess that can be set with the controls is around 1E-18. The max value is around 1E-10. That's 8 orders of magnitude difference that needs to be represented by the space between the positive and negative charges, and it looks like we have about 10 pixels distance that we can separate them at most before we loose the association between pairs. How is this representation going to work? -Chris Malley 9/27/10 6:02 PM




*Dielectric Inserted*

- When inserted, dielectric changes capacitance (and hence charge, etc.)
    - Charge shown is the charge on the cap plate
    - Charge and other quantities also change when dielectric constant is changed
- Dielectric also develops its own "effective" surface charge
    - Here we just show this as a surface charge
    - Technically, it is due to polarization of atoms in the dielectric, but this could be difficult to show. Can discuss.

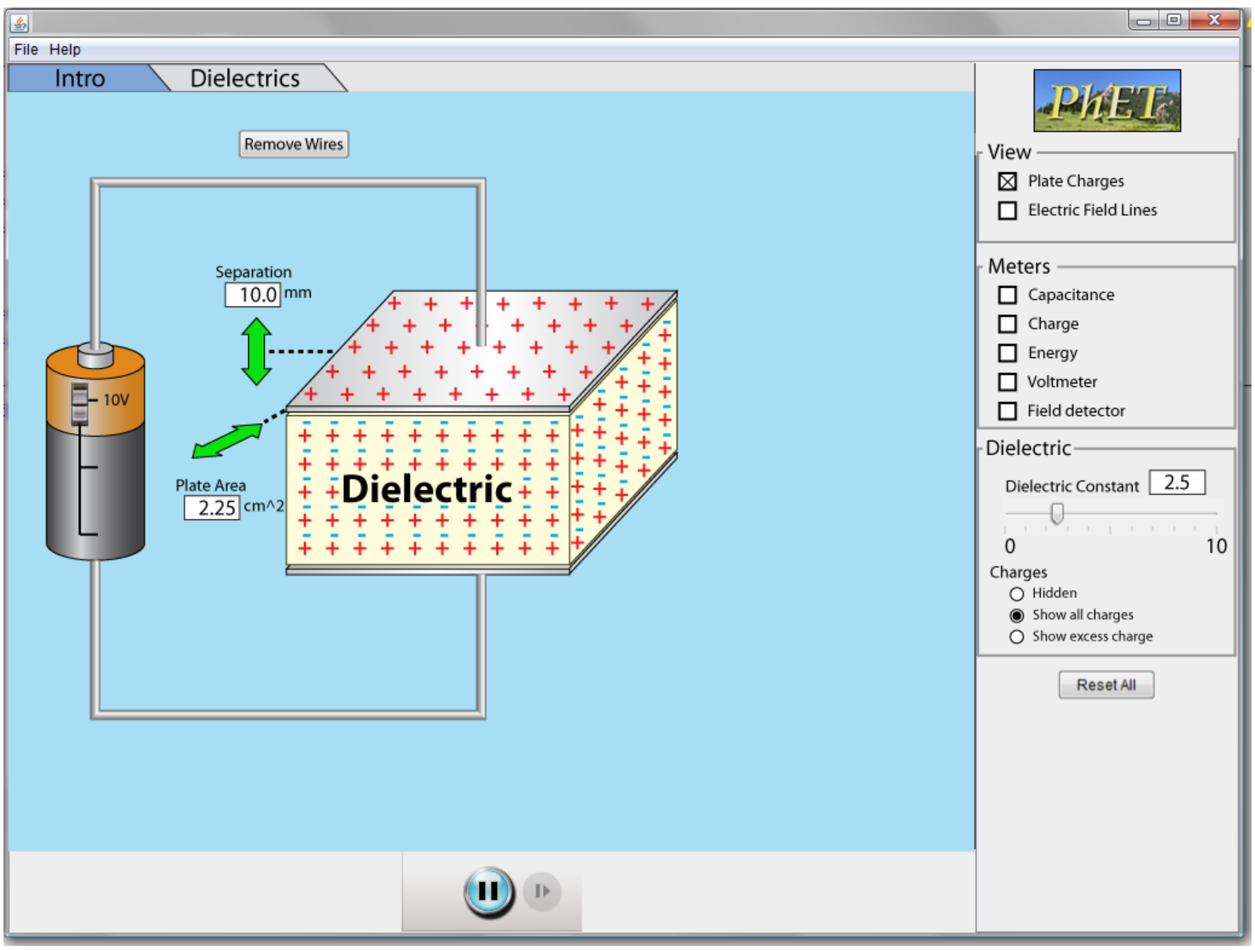
Need to figure out how E-field is going to be shown here - hard to show inside dielectric, unless we make it transparent. Probably suffice to just show on front / right surfaces. -Noah Podolefsky 4/5/10 12:28 PM

KP: I'm not really in favor of calling it a surface charge – seems like it would send the wrong message. I'd rather do something like say "show all charges", then show "net charge" - which would only display surface charge as you have here.

I changed to use terms in Optical Tweezers, "show all charges" and "show excess charge" -Noah Podolefsky 4/12/10 12:53 PM

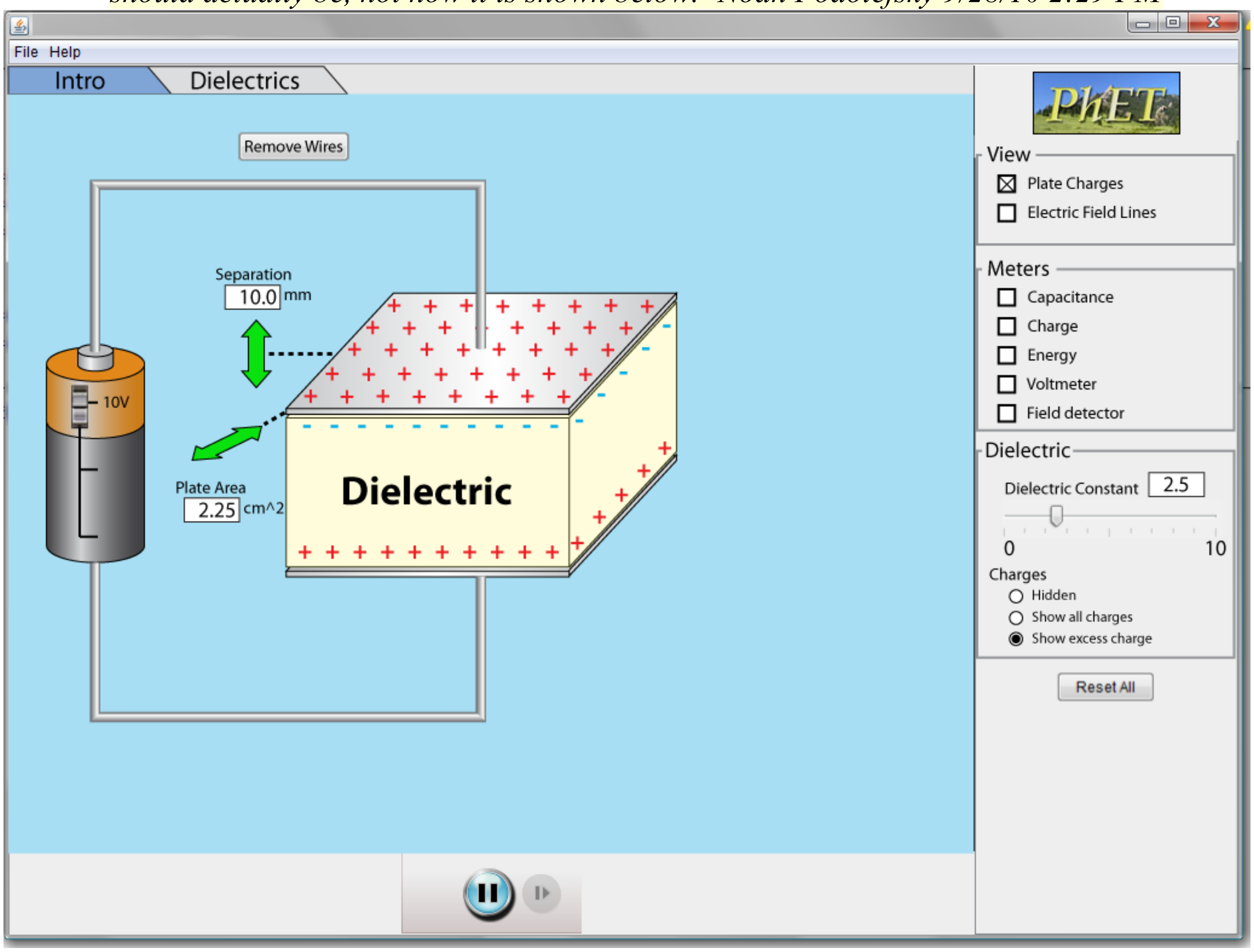
General – applies to all tabs: KP: should be able to hide charges as well. So perhaps it should have section called "View" … then just check boxes for "Electric Field Lines" and "Plate Charges" – probably need to discuss this more.

Tried to implement this in new design - open to feedback on how this looks -Noah Podolefsky 4/12/10 12:04 PM



### *Show Excess Charge*

- Shows only the excess (net) charge near the dielectric surface
- Number of + and - are equal
- Here, the number of + and -'s on dielectric surface changes proportional to $Q_{excess}$ (excess plate charge) Noah P changes this today, number of charges shown is proportional to the sqrt of Q_excess.  -Chris Malley 10/4/10 4:48 PM
- Range of Q_excess varies by 8 orders of magnitude (see above).  So how can we possibly make the number of charges shown proportional to Q_excess?  -Chris Malley 9/27/10 6:22 PM
- *Make sure that dielectric surface charge is smaller than plate charge - this is how it should actually be, not how it is shown below. -Noah Podolefsky 9/28/10 2:29 PM*



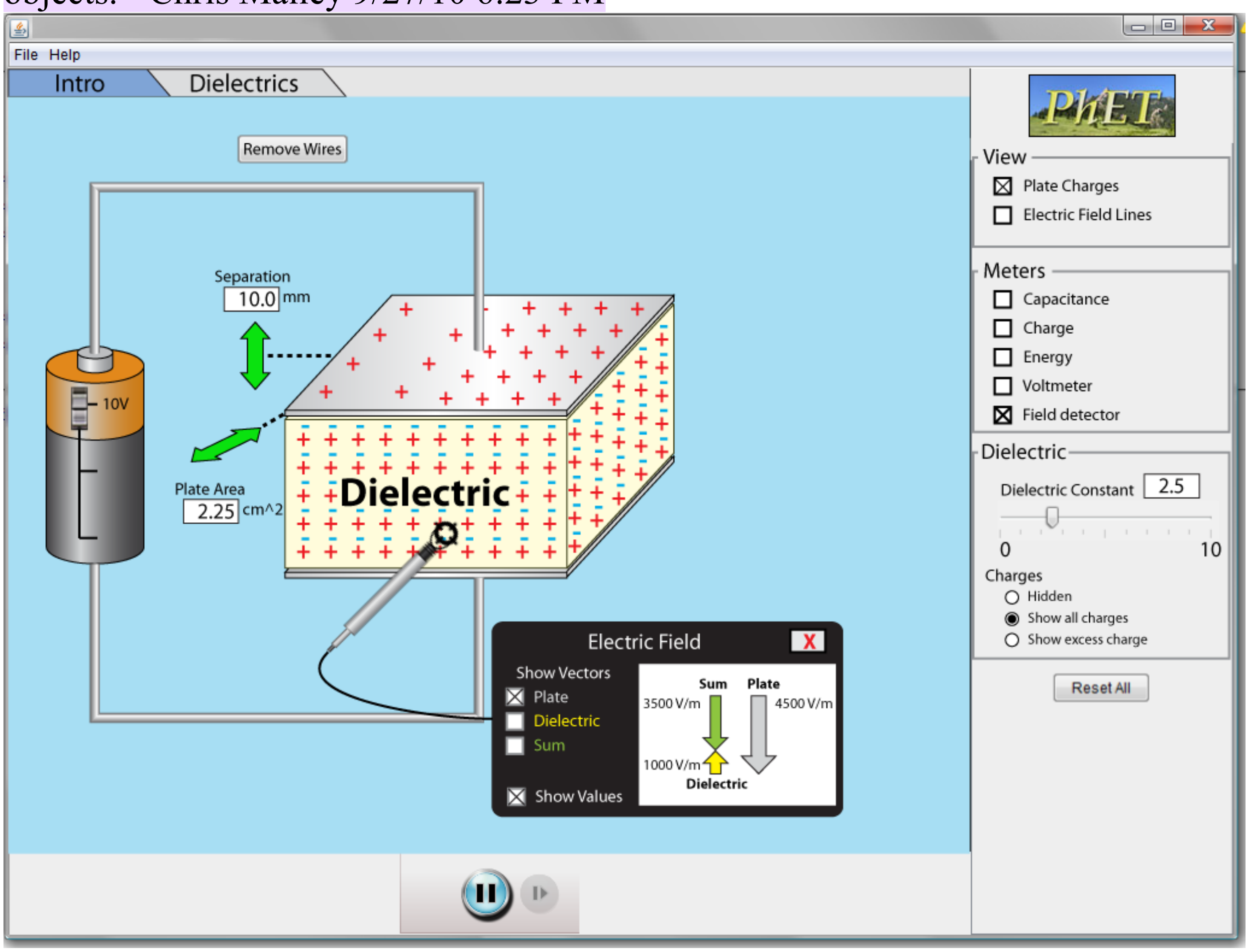

### *Field detector*

- With dielectric, field meter has a number of options
- Probe works the same as described above without dielectric

- This detector has more room to show 3 vectors with labels and values.
- Detector has a box that shows vectors for field from "Plate", "Dielectric", or "Sum"
    - "Plate" is given by E_plate_air or E_plate_dielectric (depending on where probe is placed)
    - "Dielectric" is given by E_air or E_dielectric (depending on where probe is placed; *note that E_air will be very small compared to other vectors*)
    - "Sum" is given by E_effective
    - These are color coded and labeled
    - Arranged to show that sum is *vector sum* of plate and dielectric fields
    - Starts with "Sum" checked, other vectors not checked.

Right now it looks like meter probe is outside of dielectric - maybe OK, but might be misleading. -Noah Podolefsky 4/12/10 12:58 PM

The probe should be in the same 2D plane as the wires. There's no way that this view is going to be interpretted that way.  It is unambiguous - all of the visual cues indicate that the probe is on the outside surface of the dielectric.  Same interpretation will apply when sliding the probe across the right side of the dieletric, or across the surface of the top plate -- the probe is on the surface or these objects.  -Chris Malley 9/27/10 6:23 PM

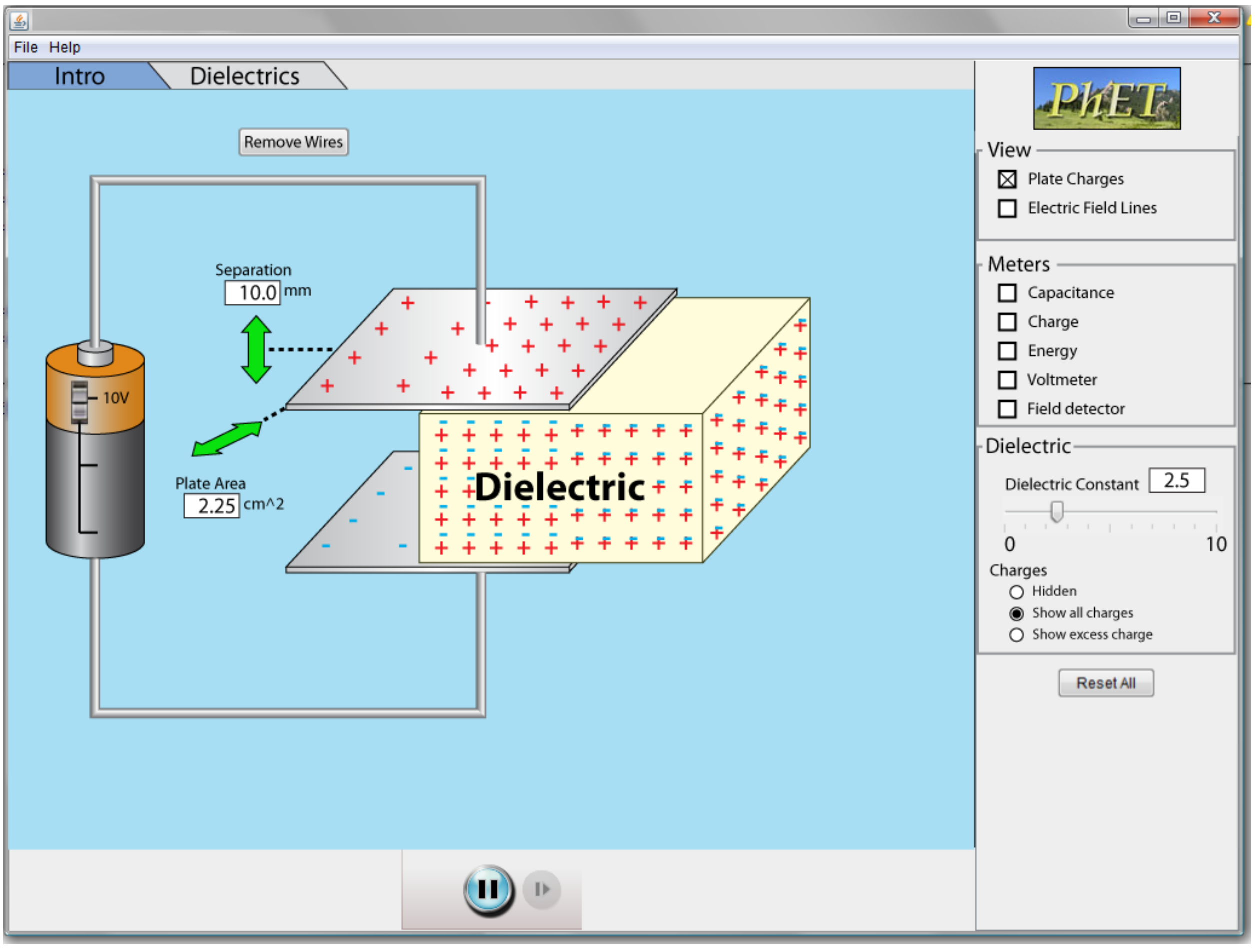


*Dielectric Partially Inserted*

- When partially inserted, dielectric only affects cap area directly above and below
  - Essentially, this acts like two caps in parallel (divided at edge of dielectric)
  - Charges will need to be shown corresponding to different areas, as in image below
  - Dielectric outside of cap shows charge separation
  - Inside, charges are separated
- E-field also need to be shown in different areas

Not exactly sure how this will work - could be tricky, need to discuss -Noah Podolefsky 4/5/10 12:31 PM

KP: This will be cool!




KP: We also were going to show the "power or energy stored" somehow I believe – I

also recommend a bar graph readout along with a value for this as well.
OK, I'll think about how to implement this. Already becoming a bit loaded in terms of check boxes and things to see....but might be OK to add one more check box for energy -Noah Podolefsky 4/12/10 12:07 PM
Same concerns as above "bar graphs". What's the range? Can it fit in the allotted space? etc. -Chris Malley 4/13/10 9:13 AM

KP: A thought to consider though I don't have strong opinions on it … perhaps we should start this in a "Qualitative Mode" where numbers are not displayed on most things, and then have a "Show Values" check box which adds numbers? Reasoning would be for students to focus on relationships as opposed to numbers (but maybe they will anyway if we give them the bar-graph representations).
I agree - I made initial sim state with all off, except for showing charges -Noah Podolefsky 4/12/10 12:07 PM
It sounds like Kathy is asking for a global "quantitative mode" control. The only "Show values" control I see is specific to the Electric Field Meter, and does not address the battery voltage, voltmeter, etc.-Chris Malley 4/13/10 9:14 AM

KP: Does battery switch directions? I don't think it needs to per se, just wondering what you all think.
Yes, battery should switch directions -Noah Podolefsky 4/12/10 12:05 PM
How does this happen? Is there a control for the battery direction? Or does the battery slider go from -10 to +10 volts? -Chris Malley 4/12/10 12:26 PM
Battery goes from -10 to + 10V, just like in Faraday. -Noah Podolefsky 4/13/10 10:42 AM

## Tab 3 - Multiple Capacitors

cmalley added:
Notes from 3/25/10 status meeting (Noah P. was not present):
(1) design needs to leave open the option of showing electrons, since it's possible we may later decide that they need to be shown
(2) design needs to leave open the option of showing particulate view of the dielectrics
(3) consider adding a tab that demonstrates capacitors in some very simple/common circuits. This would be different from CCK in that the focus would clearly be on the capacitor.

KP: One idea/extention would be to allow someone to disconnect battery, and instead select bulb and reconnect – as alternative representation of energy stored.
Chris: Do you thoughts on an "Application" tab?
I like idea of attaching a bulb...although this means we'd have to make the sim model time dependent. Also, most capacitor applications are filters, which also requires time dependent model and is probably beyond the scope of this sim. Could have another sim specifically on RC circuits - this might be covered in CCK, but CCK doesn't have anything specifically about filtering circuits -Noah Podolefsky 4/12/10 12:09 PM
I have no definite ideas for the application tab, probably a question better asked of those who will use this for teaching. I just feel that it's all rather theoretical, and it would be nice to see some applications of the theory -Chris Malley 4/12/10 12:27 PM

On issue of adding a bulb, Chris M said: `This is a nontrivial feature, so there would be a significant cost. But I'm afraid I can't precisely quantify that cost since my head has been out of this sim for many weeks. Qualitatively, the cost would be "medium", but not "huge". If forced at gunpoint to quantify, I'd say 10-20 hours.` -Noah Podolefsky 9/3/10 8:20 PM

## *Multiple Capacitors Initial State*

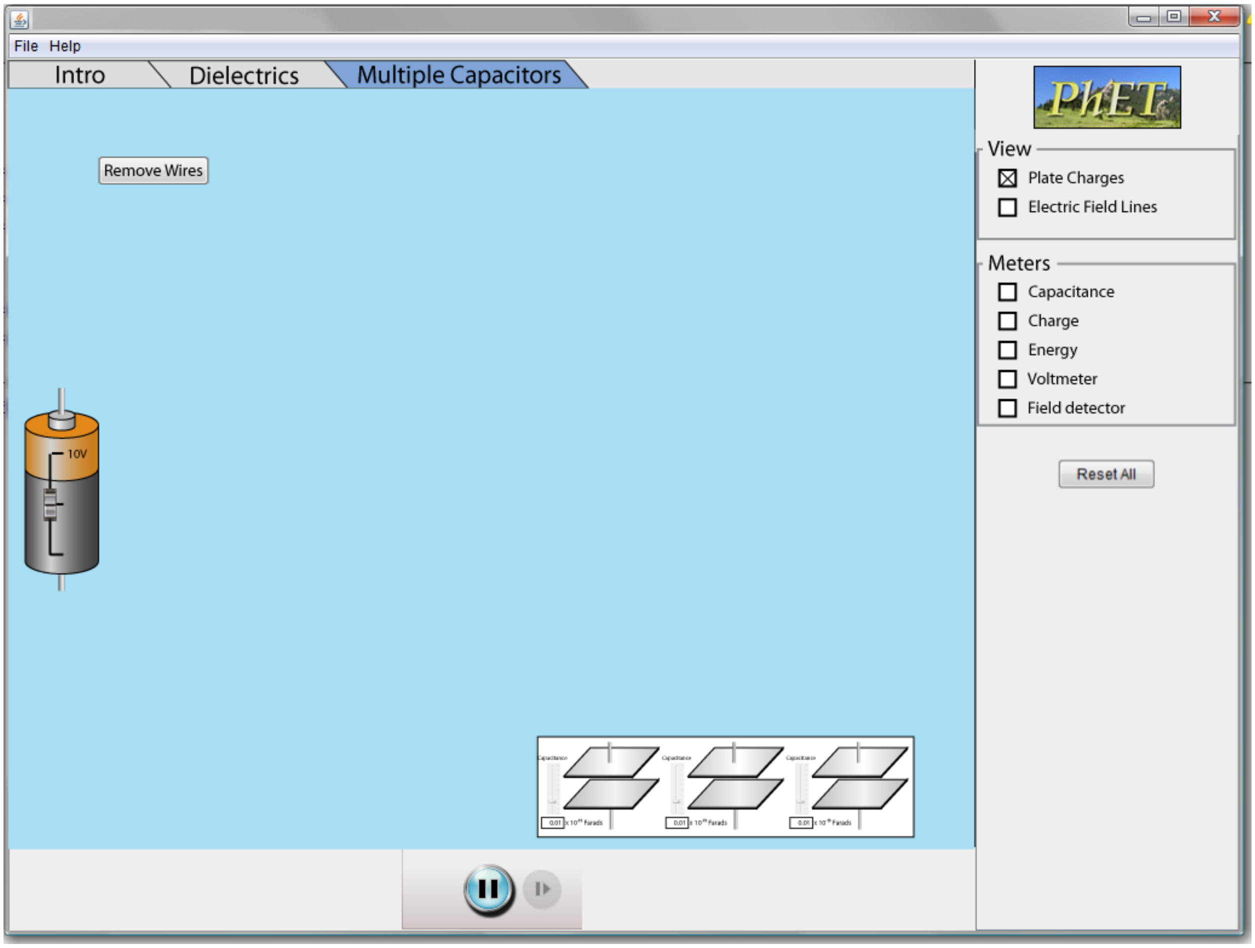
- **Learning goals are:**
  - **to be able to predict the capacitance, charge, voltage, etc. for capacitors arranged in various configurations (series, parallel, combination)**
  - **be able to measure various quantities related to combinations of multiple capacitors**
- **I have not implemented the "connect bulb" feature, as discussed above. Need to think about how this would work. Let's get the rest figured out first. Anything like adding a bulb will be in another (4th) tab, not in multiple caps -Noah Podolefsky 3/10/11 3:47 PM**
- **There are no dielectrics in this tab. I think this is a useful simplification.**
- **There is no "Remove Wires" feature in this tab. Again, probably a useful simplification. What happens when you disconnect multiple capacitors is not trivial.**

- All components are reduced in size to make room for 3 caps.
- All components are always present. As a first pass, the different capacitor configurations will be selectable from a panel of radio buttons. Once this works, we will consider implementing the drag-n-drop feature for multiple caps -Noah Podolefsky 3/10/11 3:48 PM
  - **User grabs capacitors from the box at bottom.**
  - Each capacitor can go into one of two places, indicated by yellow boxes.
  - Transparent wires appear while capacitor is held over yellow box, to indicate how the capacitor will be hooked up when dropped.
  - When dropped on a yellow box, wires automatically attach (as shown below).
  - If capacitor is dropped outside of yellow box, it goes back to the tool box.
  - If a capacitor is grabbed from circuit, it detaches wires and yellow boxes appear again (same state as if you grabbed the capacitor from the tool box).
  - Special case for series-parallel capacitors.
    - There are two possible configurations for series-parallel.
    - When the 3rd capacitor is dropped, a box appears that allows the user to "Choose Arrangement" of the capacitors. Clicking one of the two options makes the wires attach accordingly.
- Capacitances can be changed with a slider / text box for each cap
  - All capacitors have the same area
  - This is to simplify, since in this tab all we care about is capacitance of each.
  - Changing capacitance only changes separation.
  - Capacitance only changes by a factor of 3x.

    - Choose a range that makes it easy for users to see 2x or 3x on meters, while still resulting in a good looking visual representation of charge, E-field, etc.
- Delete "remove wires" button from this tab.
- All meters are still available.
    - **The mock ups below should allow the meters to appear in their default positions**
    - Capacitance meter shows the *total capacitance for all capacitors connected to battery*. Any cap not connected is not included in the calculation.
    - Charge meter shows the *total charge stored*.
        - Calculate this from $Q = C V$, where C is total capacitance for all caps connected to battery, V is battery voltage.
        - This will give the total charge that has been taken from the battery and stored in the capacitors.
    - Energy is also the total for all caps connected to battery.
        - Use $U = 1/2 C V^2$, where C is total capacitance of all caps connected to battery, V is battery voltage.
    - Should be able to place voltmeter probes anywhere and get an accurate reading.
        - This will require some algorithm for figuring out voltage across each cap, which shouldn't be too hard (but I haven't figured it out yet
    - I left the *Field Detector* check box in, since we might still want that. However, I think it is going to be hard to implement, and not sure it is that useful in this tab. Might consider removing it.

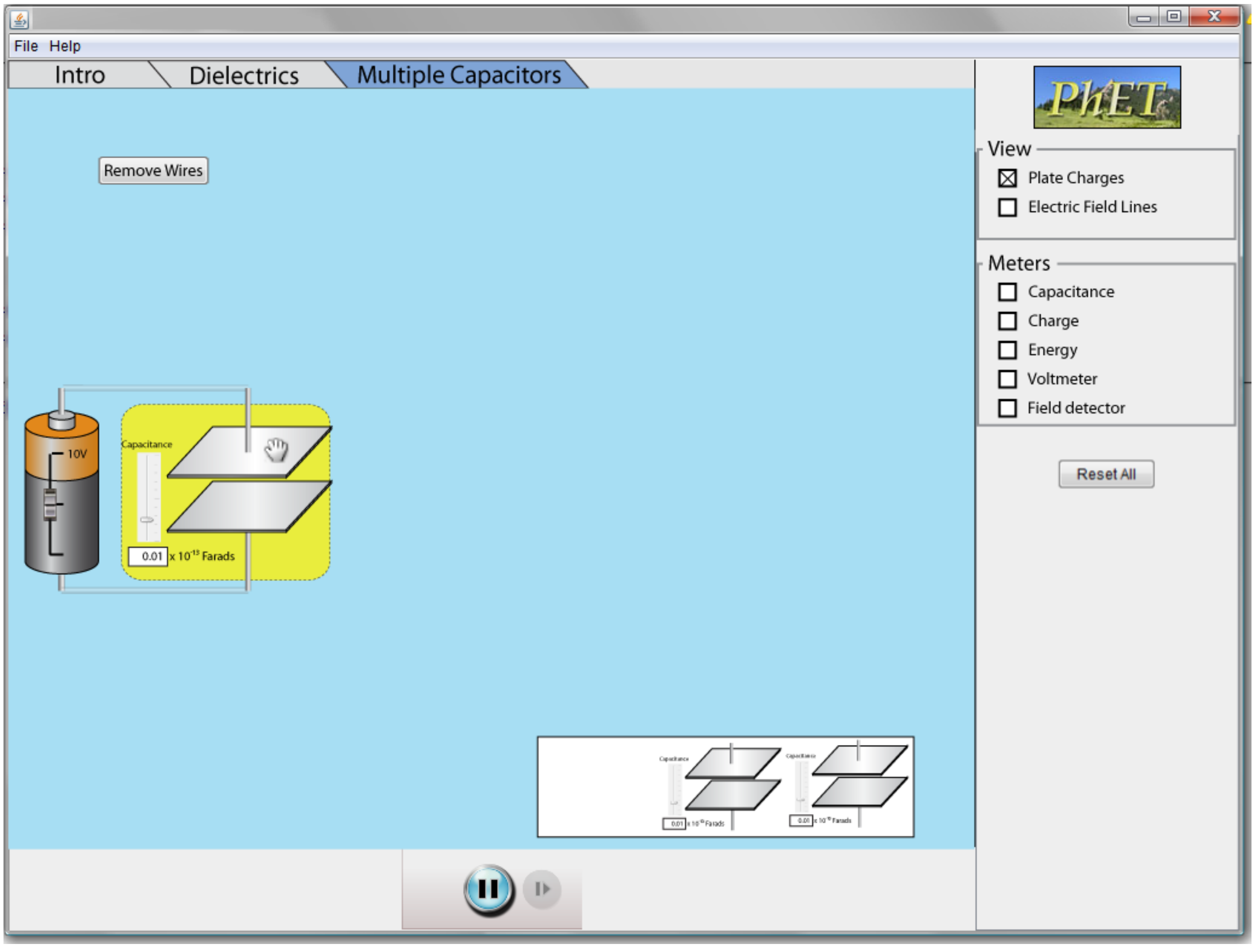
## *Start State*

- Play area is blank, only battery shown and box with 3 small capacitors.



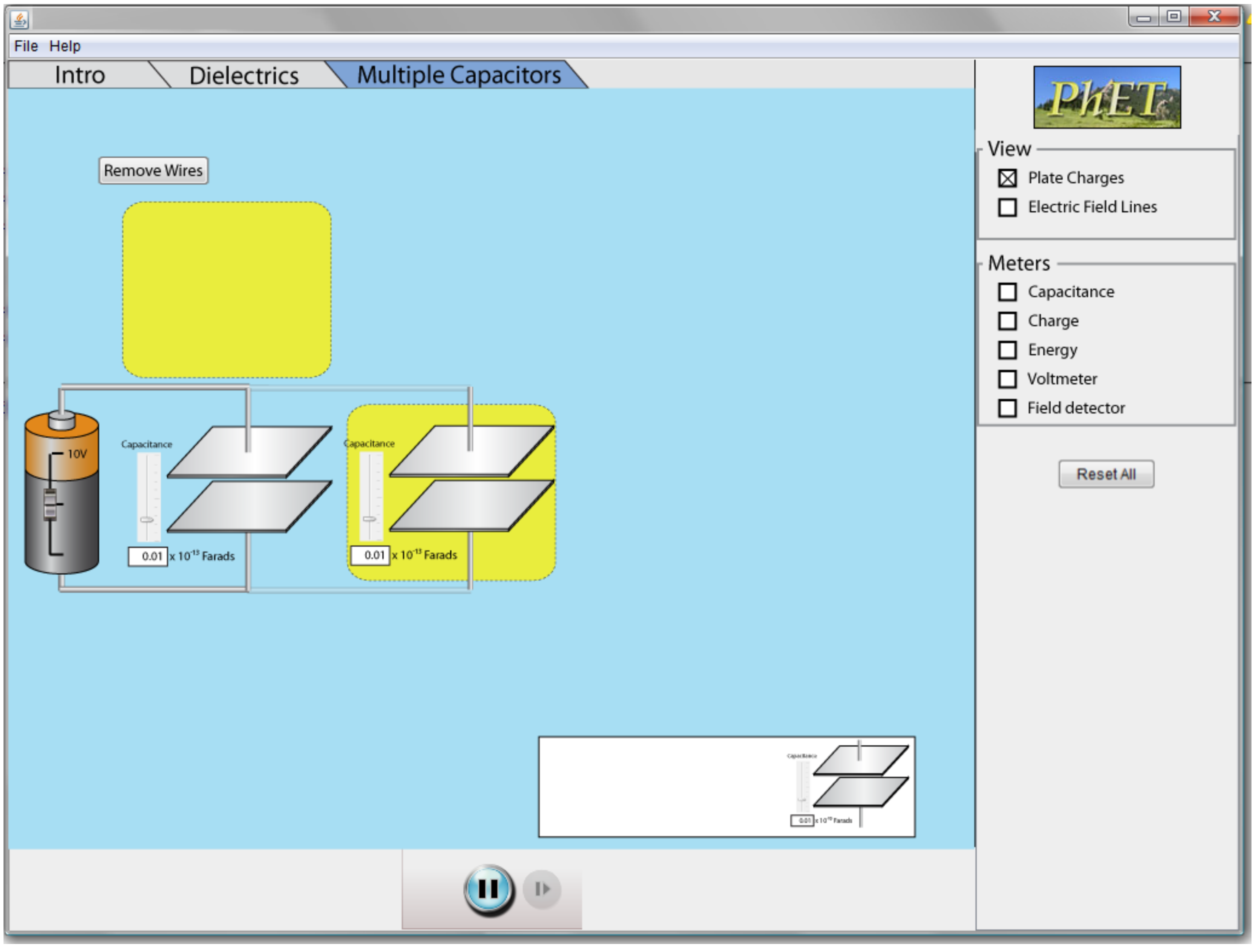

*First Capacitor Dragged Out*

- Tab starts up with just battery, all capacitors in box. Play area is blank.
- When a capacitor is dragged out, yellow box appears.
- Only one place for the first capacitor - directly right of battery.




*Second Capacitor*

- Second capacitor can be placed in series (top box) or parallel (right box).
- Again, transparent wires are shown, then attached when the capacitor is dropped.

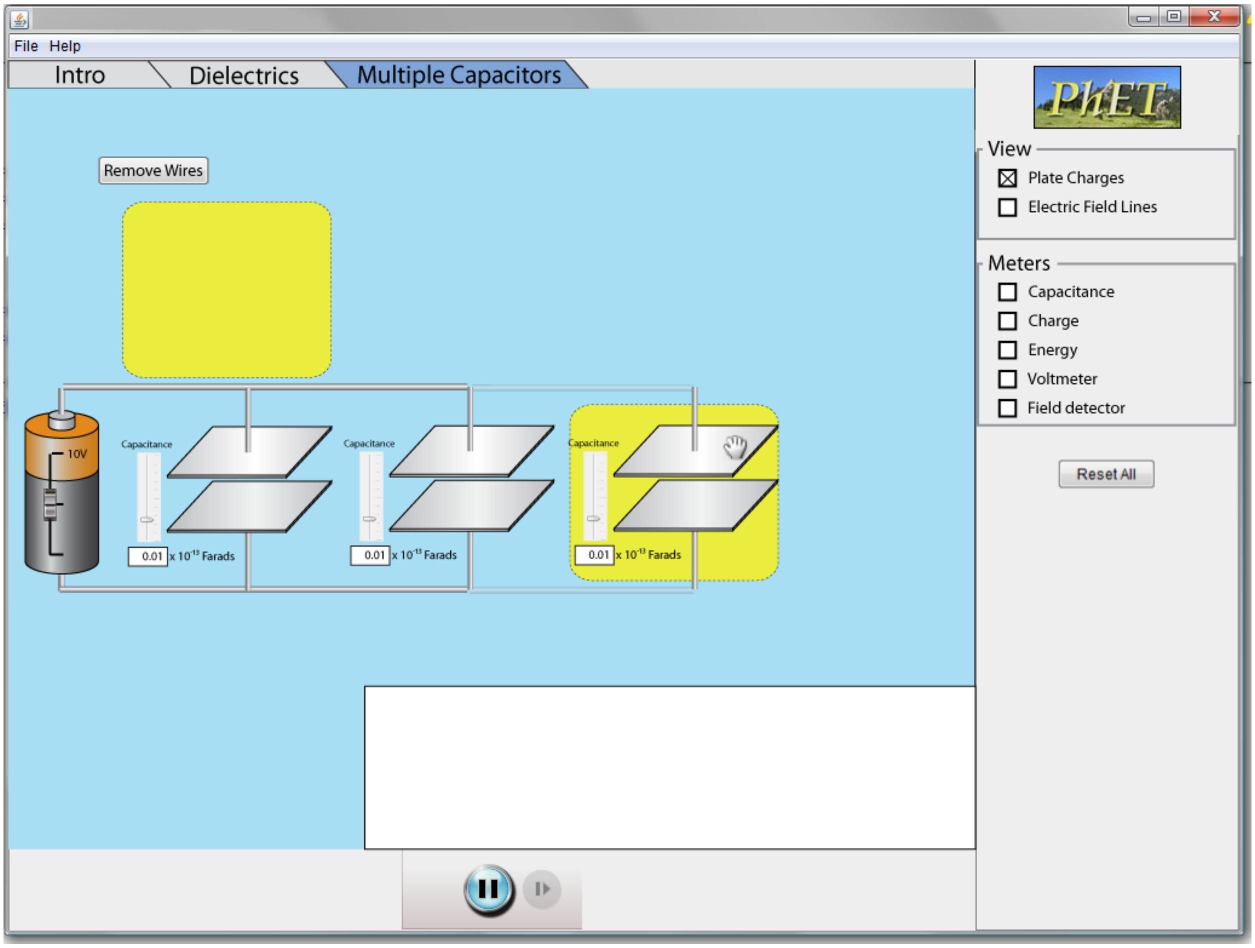



*Third Capacitor*

- If first two were parallel, 3rd capacitor can be dropped in parallel or in series/parallel combination.
- If first two were series, 3rd can be in series or combination.
- If user drops in "combination" box, a dialog appears to "Choose Arrangement". (see below).

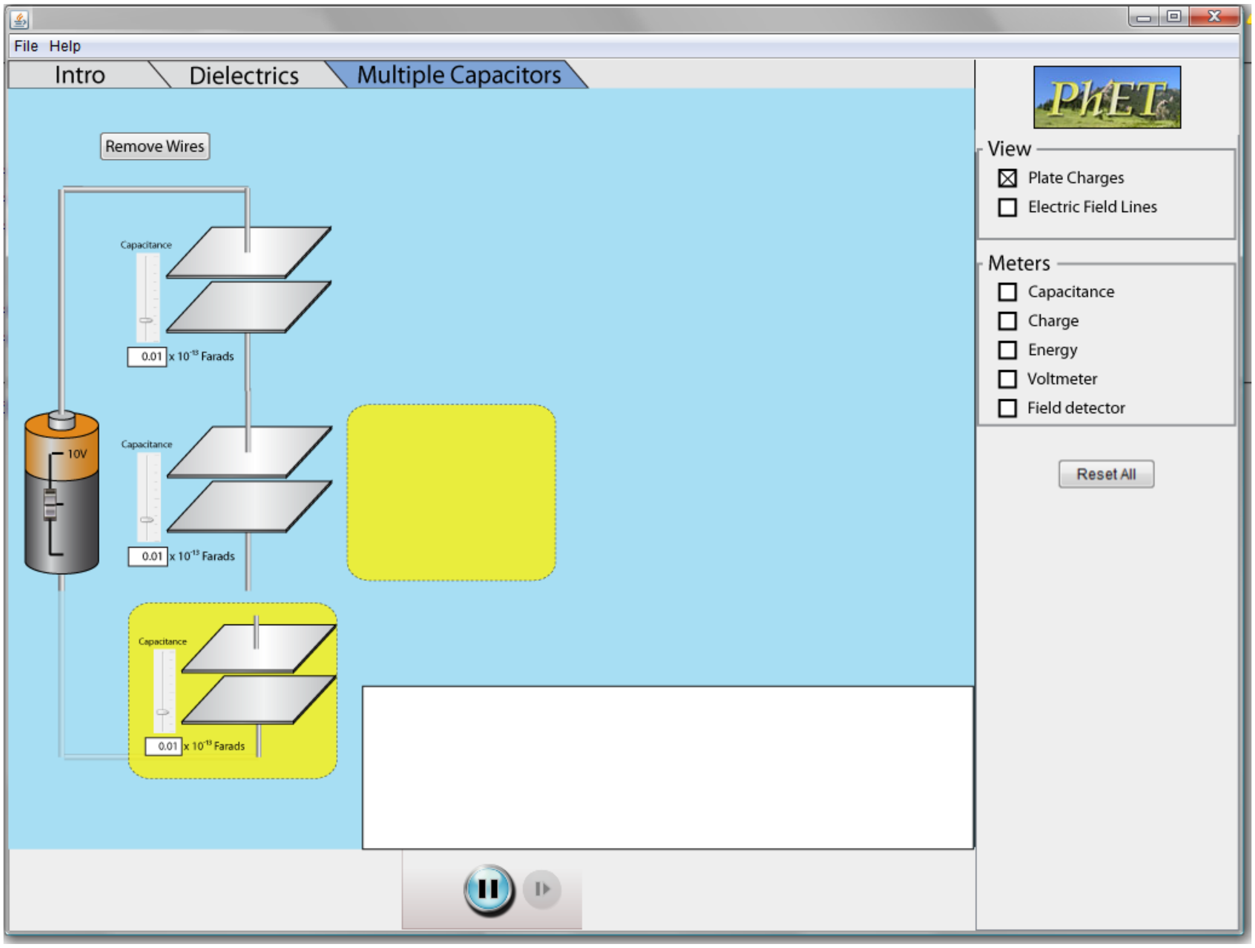
Multiple Capacitors in Parallel

- "Three in Parallel" shown below
- "Two in Parallel" leaves out one capacitor
- Total capacitance is: $C_total = C_1 + C_2 + C_3$ (leave off $C_3$ for two caps)
- In this case, simple to figure out charge.
  - Voltage across each capacitor is the same
  - Charge on each is given by $Q_i = C_iV$, where $C_i$ is capacitance of individual capacitor and V is the battery voltage



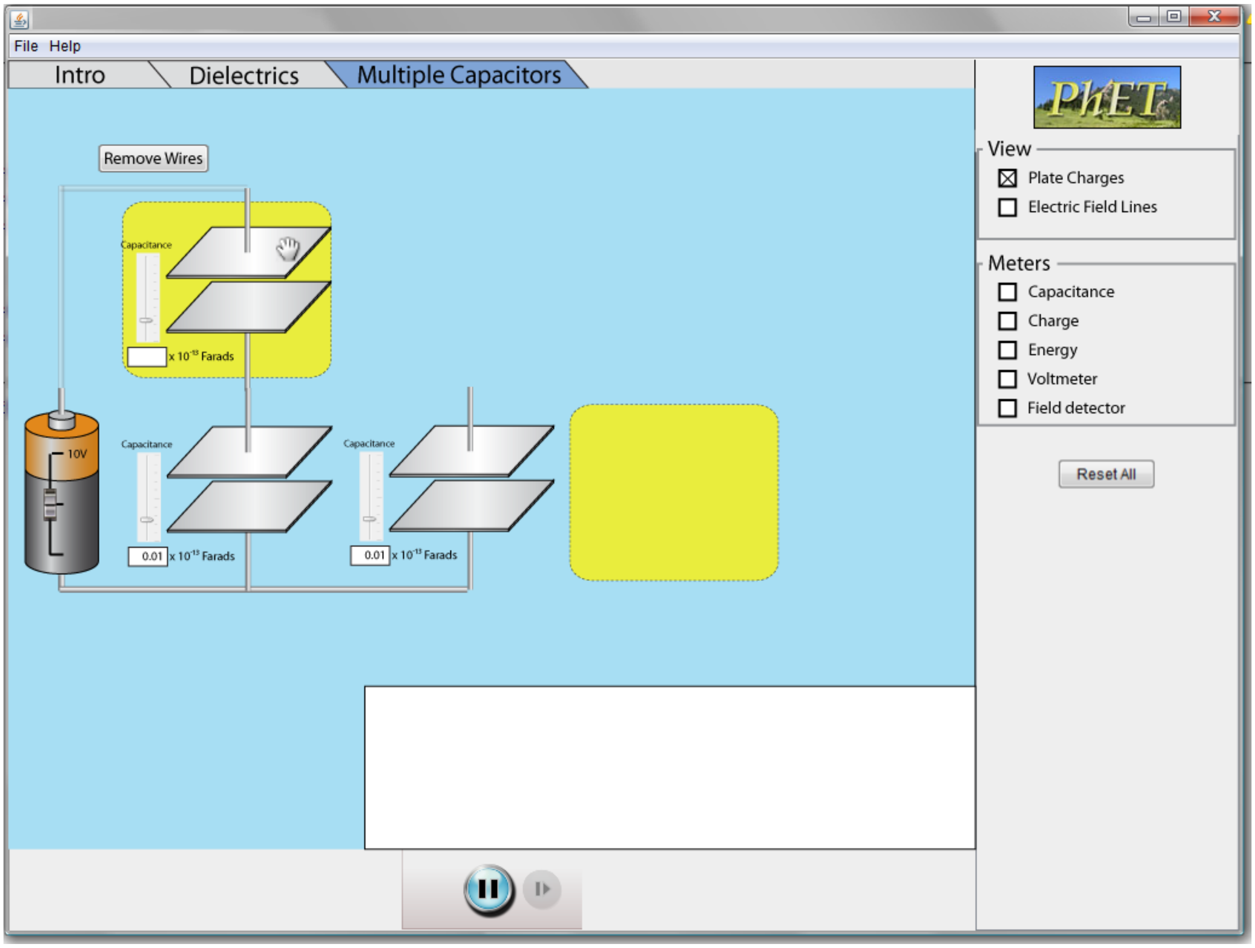

Multiple Capacitors in Series

- "Three in series" shown below
- "Two in series" is the same but only 2 capacitors
- Total capacitance in series is: $C_{total} = \dfrac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}}$ (leave off 1/C3 term for two caps)
- In series, each capacitor has the same plate charge (Q)
- The voltage across an individual capacitor is given by: $\mathbf{V_i = Q / C_i}$, where Q is the plate charge and $C_i$ is the capacitance of an individual capacitor (each cap will have a different V if they have different C's)
- The charge on any individual capacitor is $\mathbf{Q = V_{total} * C_{total}}$ (yes, they all have the same plate charge)



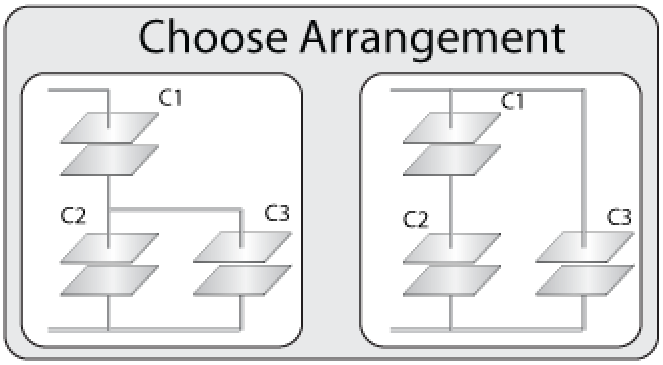

Multiple Capacitors in Combination

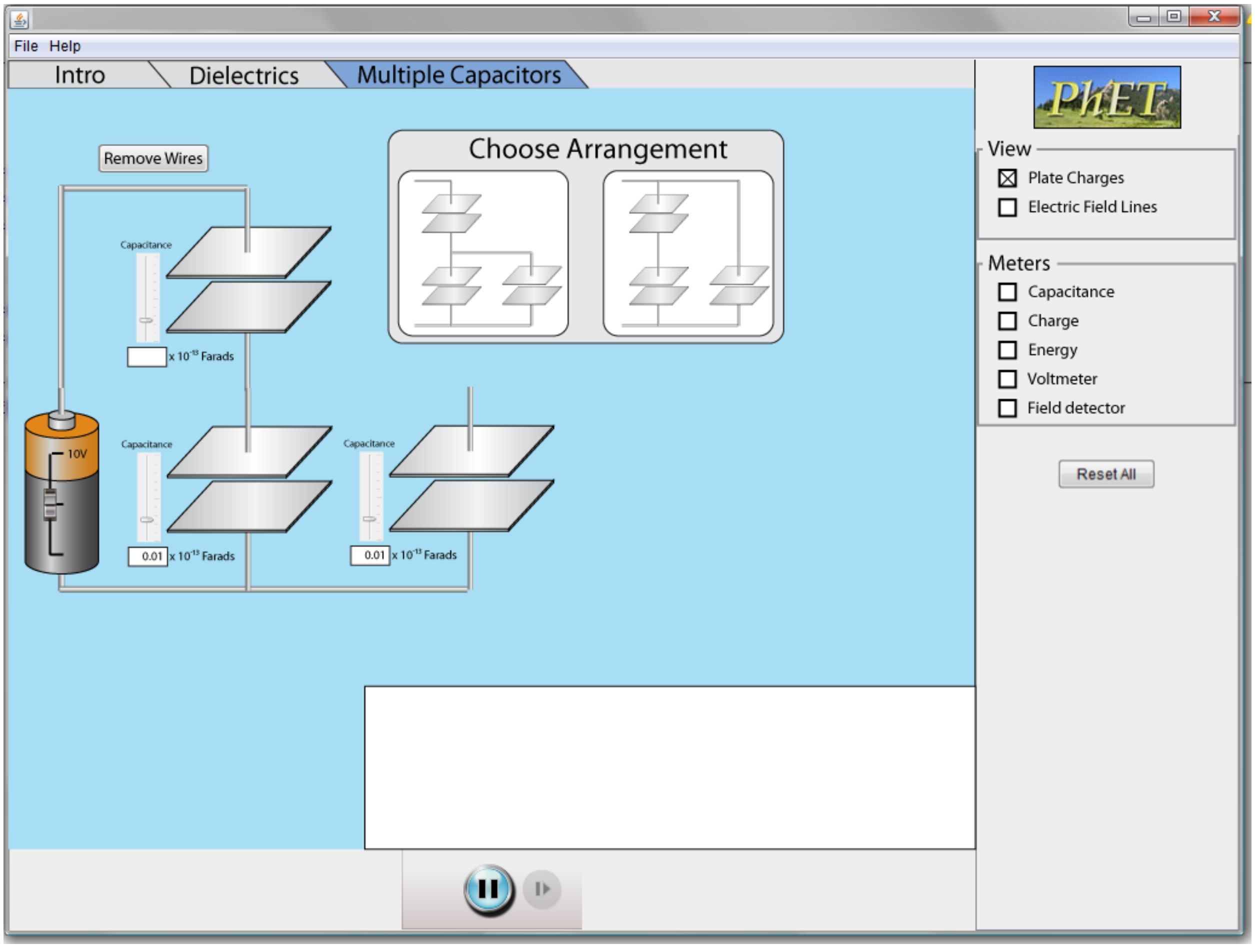
- If user drops in the series / parallel spot, a dialog appears (see below).




- Dialog box to choose arrangement of series / parallel.
- Choice on left is 2 in parallel with 3rd in series; choice on right is 2 in series with 3rd in parallel.
- User clicks one of the arrangements, then wires attach and dialog box disappears.
- There are two possible combinations for 3 capacitors: 2 in series and then in parallel with a third, or 2 in parallel in series with a third (see two arrangements below).
- For 2 parallel + 3rd in series (left box):
  - Total capacitance is given by $C_{total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2+C_3}}$, where $C_1$ is the lone capacitor on the top (in series with the other two), $C_2$ and $C_3$ are in parallel on the bottom (see small labeled image below)
  - The voltage across $C_1$ and $C_2$ (in parallel) is the same.
  - Treat these as a single capacitor with equivalent capacitance $C_{eq} = C_2 + C_3$.
  - In this case, the plate charge (Q_total) individually for C1 and $C_{eq}$ is the same as the total charge for the whole circuit (given by $Q\_total = C_{total} * V$)
  - Calculate the voltage across the capacitors using $V = Q / C$, where C is either $C_1$or $C_{eq}$.

- For 2 series + 3rd in parallel (right box):
    - Total capacitance is given by $C_{total} = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}} + C_3$, where $C_1$ and $C_2$ are in series on the left, and $C_3$ is the lone capacitor on the right (in parallel with the other two)
    - The voltages across the series pair and the lone $C_3$ are the same.
    - Calculate the plate charge from $Q = CV$ where $C$ is the capacitance of either the series pair (using the series formula above) or $C_3$.






## Resolved Issues Archive

**~~To discuss how a capacitor charges up and discharges in relationship to time and energy stored.~~This learning goal is covered by CCK-AC. -Katherine Perkins 3/8/10 9:07 PM**

**Other sims (eg Glaciers) spell this out as "Introduction", which is also easier to translate. -Chris Malley 3/31/10 9:50 PM Changed to Introduction -Noah Podolefsky 4/1/10 2:18 PM**

**~~For Model, will need to be explicit about how to calculate charge when voltage held constant and voltage when charge held constant ... basically always know C b/c of geometry, so use that in first equation. Also since we want to display e-field lines and vectors, will need to have e-field equation. ... E= delta(V)/d. And then calcs for E-field from plates and from dielectric~~**

**The "Capacitance" and "Charge" fields in the play area look like editable text fields, but I believe they are read-only displays. If they are indeed displays, then their values should not be presented in a white box. -Chris Malley 3/31/10 9:09 PM**

- **Agreed. I'll change this. -Noah Podolefsky 4/1/10 8:43 AM**

Is this "or" or "and". If it's really "or", these should be radio buttons. -Chris Malley 4/5/10 2:07 PM

- Changed to "and". -Noah Podolefsky 4/6/10 9:25 AM

...so the cursor should change to left-right double arrow? -Chris Malley 4/5/10 2:09 PM

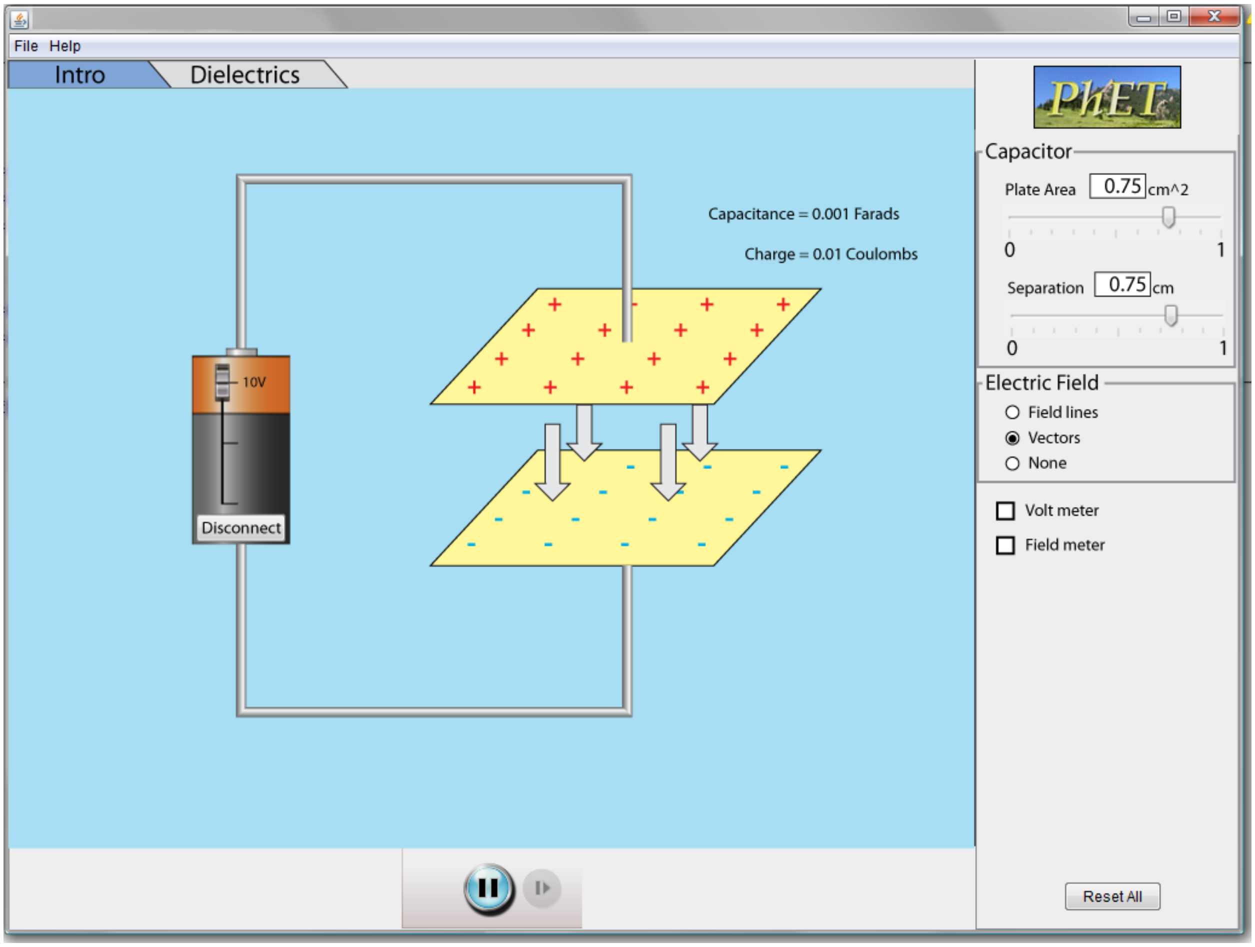
- Yes, added this below. -Noah Podolefsky 4/6/10 9:25 AM

Describe how the dielectric's size relates to the capacitor settings. Does its thickness always match the capacitor separation? Does the size of its top and bottom always match the size shown for a specific capacitor plate area? -Chris Malley 4/5/10 2:12 PM

- Added spec for this above. -Noah Podolefsky 4/6/10 9:27 AM

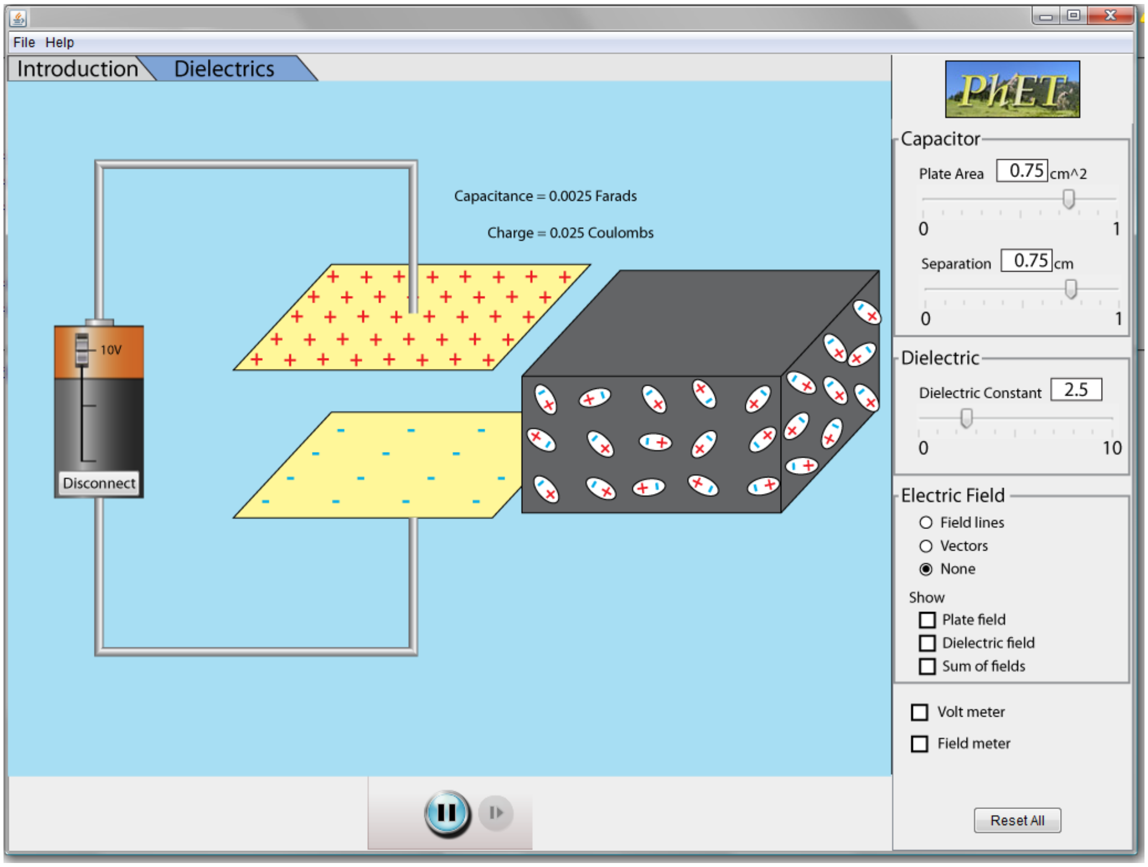
## *Field Vectors selected Removed this view, put vectors in detector instead -Noah Podolefsky 4/8/10 2:44 PM*

- Only show 4 vectors
- Size of vectors proportional to field strength
    - How many orders of magnitude difference is there between the min and max field strength? I want to make sure this is a usable representation for the full range of values. -Chris Malley 3/31/10 9:13 PM
    - See response above. -Noah Podolefsky 4/1/10 8:45 AM
    - KP: My recollection was that we thought that the “vector representation as shown here was going to be problematic
      because the vectors can get very large. We decided the “field meter” (I suggest rename) would be better way to
      show vectors, I thought.



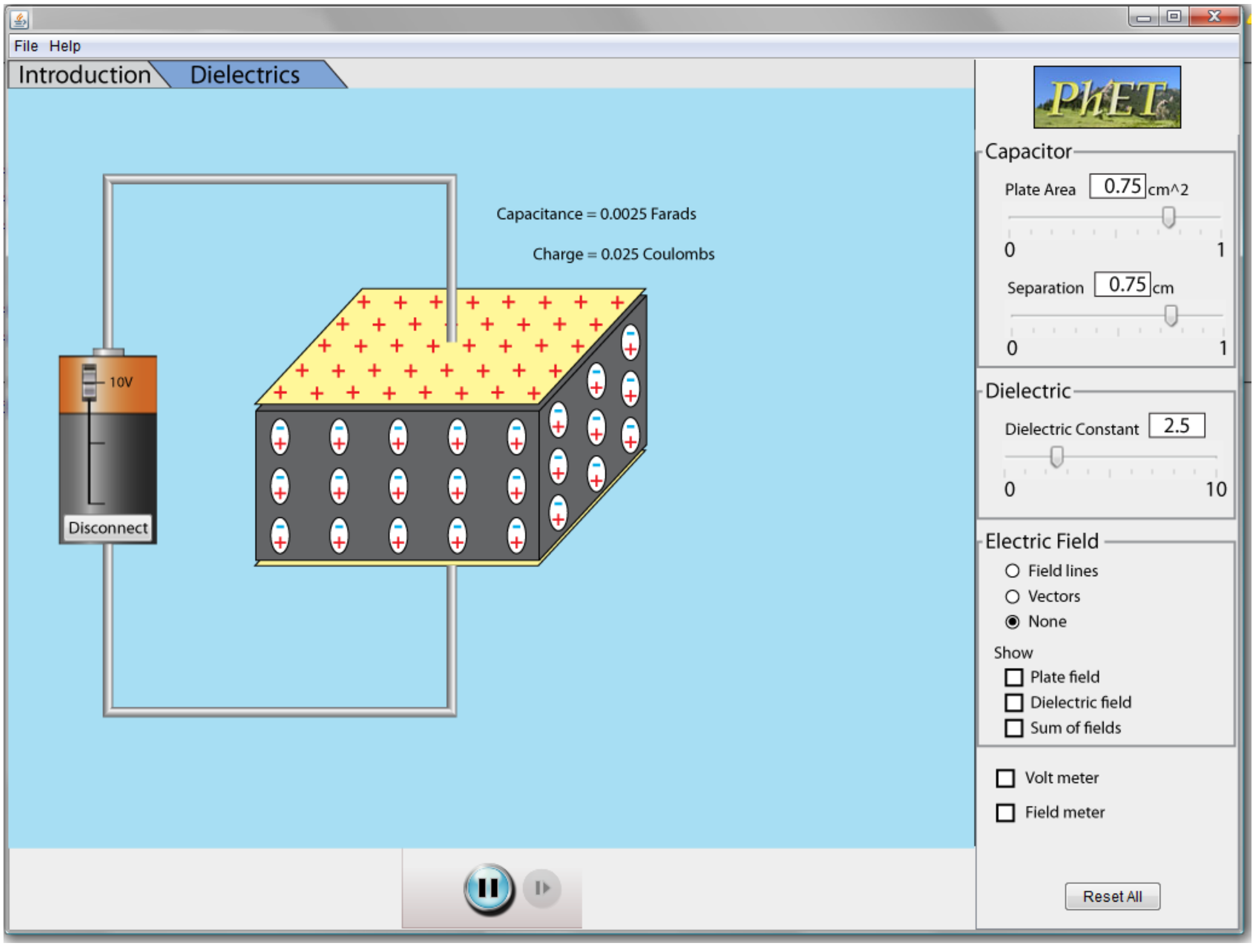

### *Another Option - Dipole representation*

- We could also represent charges as shown below (similar to this site)
  - OK to show nothing on top surface? -Chris Malley 4/5/10 2:15 PM
  - Good question - not sure - I guess that is one problem with this representation. Will need to discuss. The more I look at this representation, the less I like it. It is kind of confusing, since the "effective" surface charge is what really matters...and it might be misleading as well. -Noah Podolefsky 4/6/10 9:28 AM
- Diploes are randomly oriented when outside of cap (or with zero volts)
- Degree of alignment proportional to dielectric polarization
- See below for what this would look like with dielectric inside cap

- 


***Dipole Representation - Aligned***

- If we go with this representation, this is what would look like when totally aligned inside of cap
- Note that this is totally aligned - at smaller voltage there would be less net alignment (but more than random)

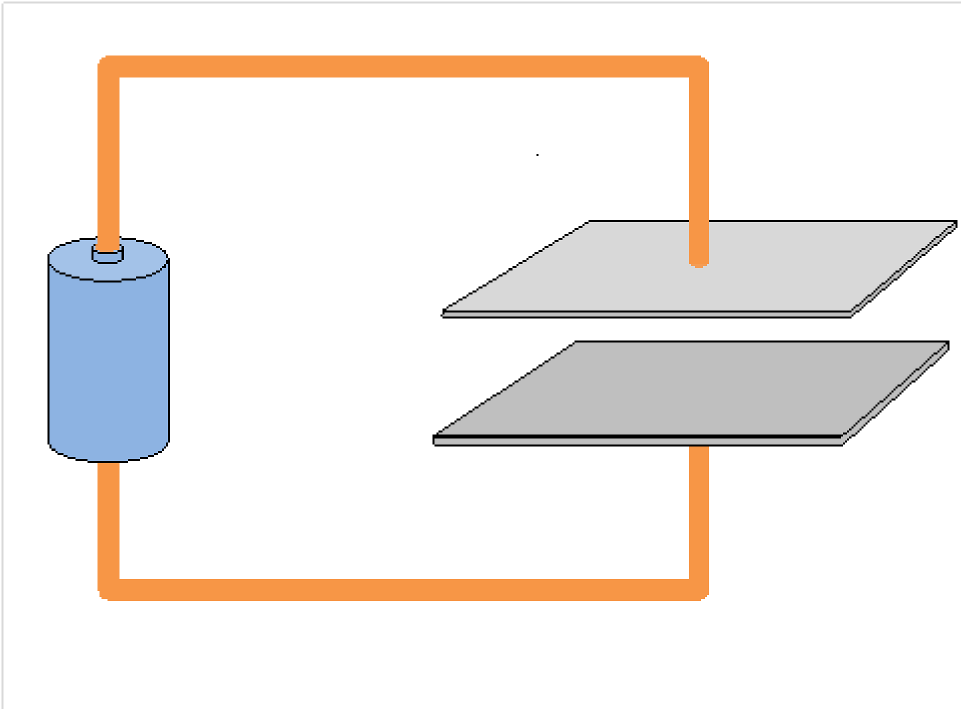



M.Dubson Comments:

I am happy with the functionality and pedagogy of this sim. My only comments have to do with the appearance of the graphic.
To me, the capacitor looks odd: Back edge of plate appears larger than front edge. It's an optical illusion; my brain expects farther things to look smaller, so it gets confused when farther things are not smaller. To make the graphic more pleasing (to my eye), I suggest

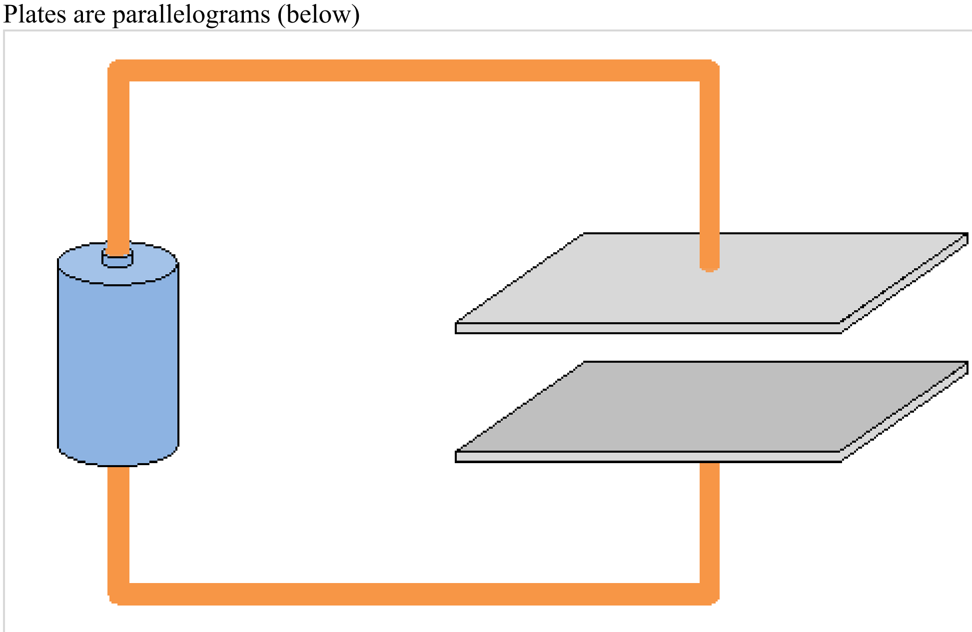
Priorities (from simplest, easiest to implement to hardest to implement):
1) Make battery 3D , same perspective as capacitor plate (see graphic below)
2) Give plates a thin edge to cue viewer as to which is near side
3) Make bottom plate just a wee bit darker than top plate. Gives viewer subtle cue that bottom plate is below top plate, slightly shaded.
4) (Difficult, I think.) Make plates 3D perspective rather than simple parallelograms. This is difficult because it requires true 3D view with vanishing point perspective, which must be maintained when plates are resized or positioned. Also will require 3D layout of charges (+) and (-) signs.
Not terribly difficult to fake in 3D. -Chris Malley 4/14/10 6:23 PM

If you cannot tell the difference between the two images below, then there is no need to do true 3D image of capacitor plates.



3D perspective view of plates (above)

Plates are parallelograms (below)



What's the title of the sim going to be? Capacitor?  Capacitors? Some more clever? It would be nice to choose a title before I create the project in SVN, since we try to have the SVN project name match the title, and changing SVN project names later is costly and painful. -Chris Malley 4/6/10 12:36 PM

I think the word "Capacitors" needs to be in the title - but I can't think of anything clever off the top of my head. -Noah Podolefsky 4/7/10 8:02 PM

- Java's standard up/down arrow mouse cursor is black, and this is the cursor used in other sims to indicate up/down motion.  If you want it to be green, we'll need to create and install a custom cursor image. I don't think this is worth the effort, and it will be inconsistent with other sims. And a bigger questions is, since the control panel has controls for this, will users ever find this feature?  It's relatively expensive to implement, so we should be confident that people will find it.  -Chris Malley 3/31/10 9:02 PM
- Black is fine by me. I was thinking of the green arrows that are used in Alpha Decay and Atomic Interactions, but these are fixed to the movable objects, not mouse cursors. -Noah Podolefsky 4/1/10 8:39 AM
- I have a feeling users will try to move the plates, not so sure they will figure out to change the area this way. In Wave Interference, users do grab the barrier and move it, even though there is also a control for this. Seems very useful in that sim. They can also change the slit width and separation this way, but for this users usually use the controls instead. -Noah Podolefsky 4/1/10 8:41 AM

Meeting between CM and NP on 5/20/2010:

- We discussed the issue of user's who try to create AC behavior by quickly dragging the battery voltage slider positive and negative.  We're not going to address this.  If someone reports this, tell them that AC is not supported by this sim, and they would need to drag the slider faster than humanly possible in order to create AC.
- There are lots of things in the play area, many of which can be resize and made visible/invisible.  As size and visibility changes, there are numerous opportunitities for things to overlap, possibly making them unusable or inaccessible.  We are  not going to attempt to programmatically prevent this, trying to automatically reposition things will cause confusion, will be very expensive, and may be impossible in many cases.  So live with it.
- Separate +/- zoom buttons on meters are not particularly useful.  They will confuse users who don't understand the meters, and annoy the users who do understand the meters, with very little (if any) middle ground where they are truly useful.  Better would be a single "autoscale" button that sets the meter to a scale that is useful for the circuit configuration.  We'll try adding this single button, and have it flash the meter's max value display as the scale is changed.