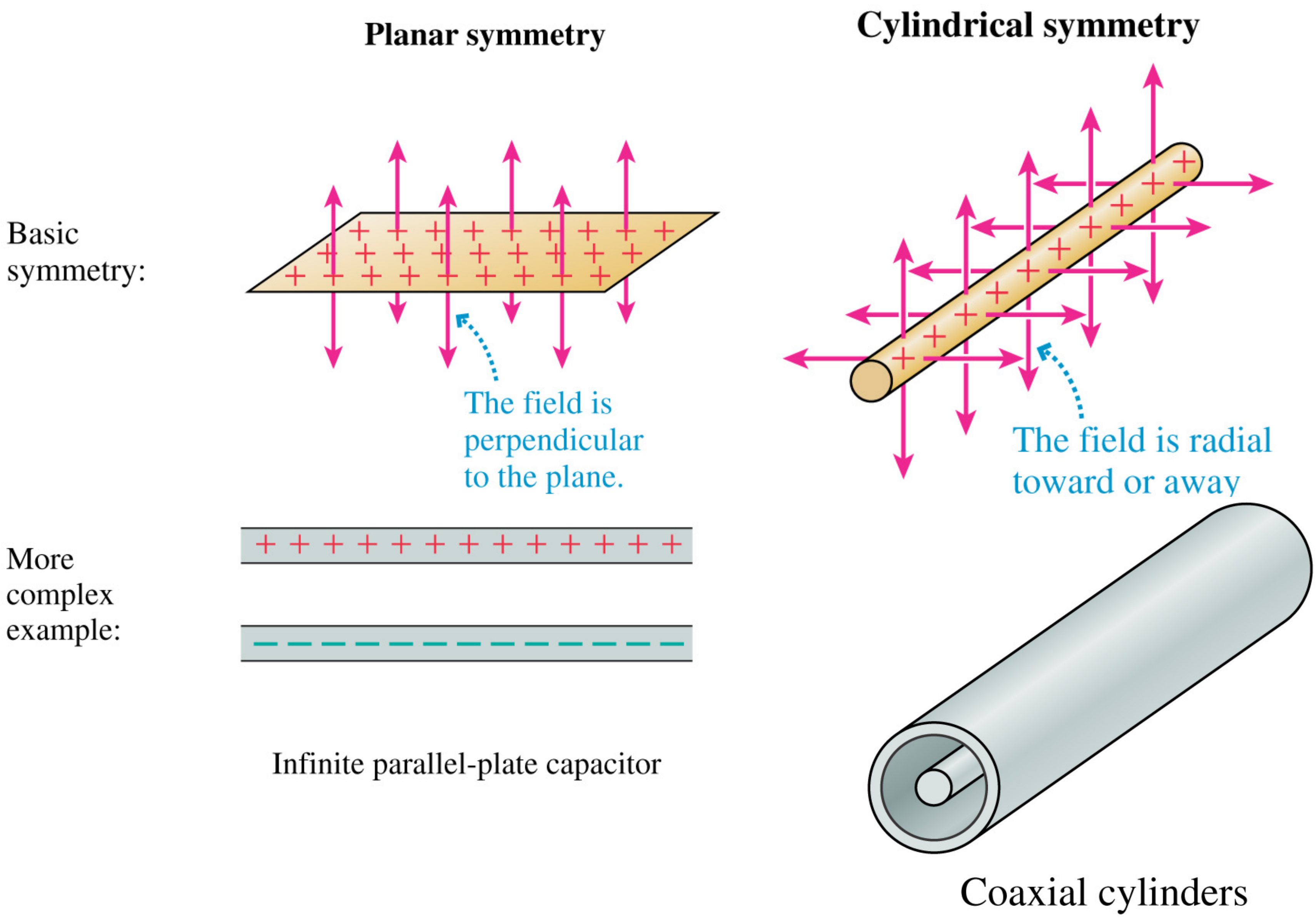
PHY294H

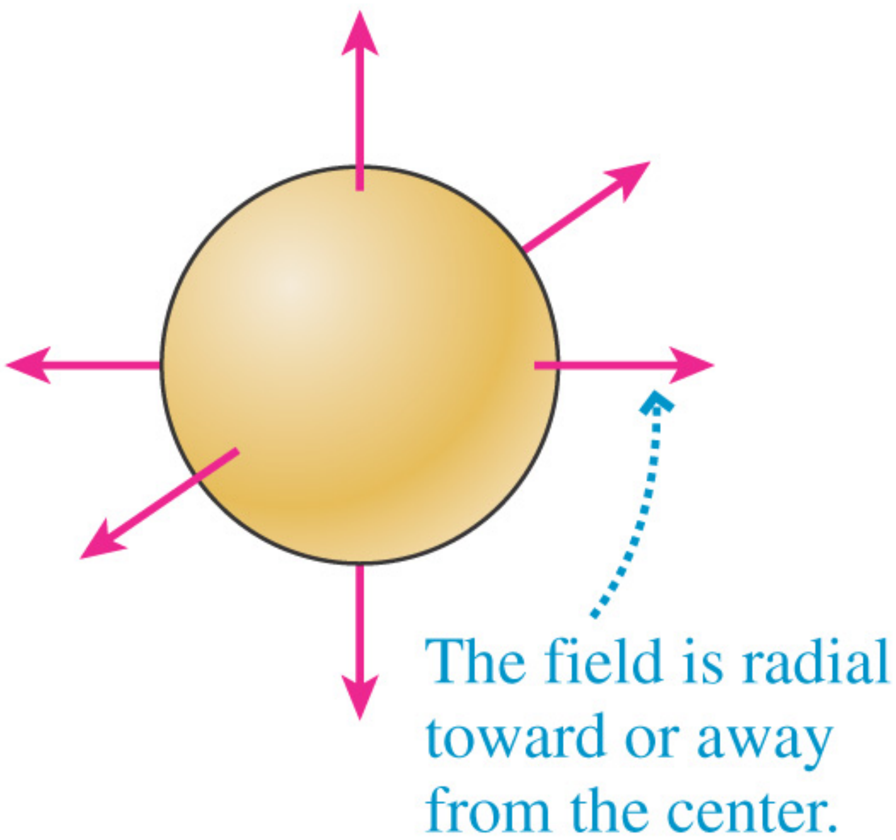
- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
    - **2nd MP assignment due Wed Jan. 27; second hand-written problem (27.51) as well; I added it on to the MP assignment for convenience, but it still needs to be turned in with a complete solution**
    - **Help-room hours: 12:40-2:40 Tues; 3:00-4:00 PM Friday**
- Quizzes by iclicker (sometimes hand-written)
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
    - lectures will be posted frequently, mostly every day if I can remember to do so

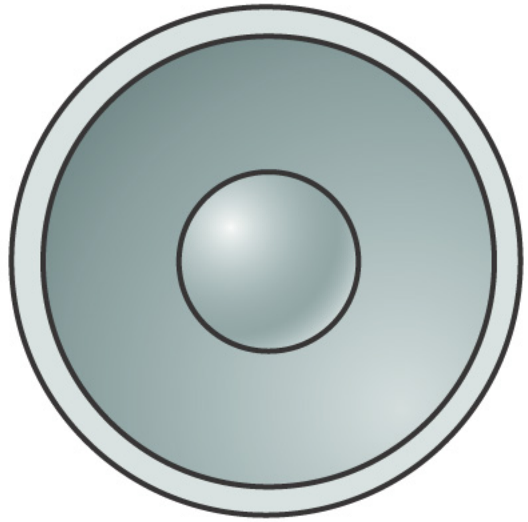
Symmetries you' ll encounter



Symmetries you'll encounter

Spherical symmetry

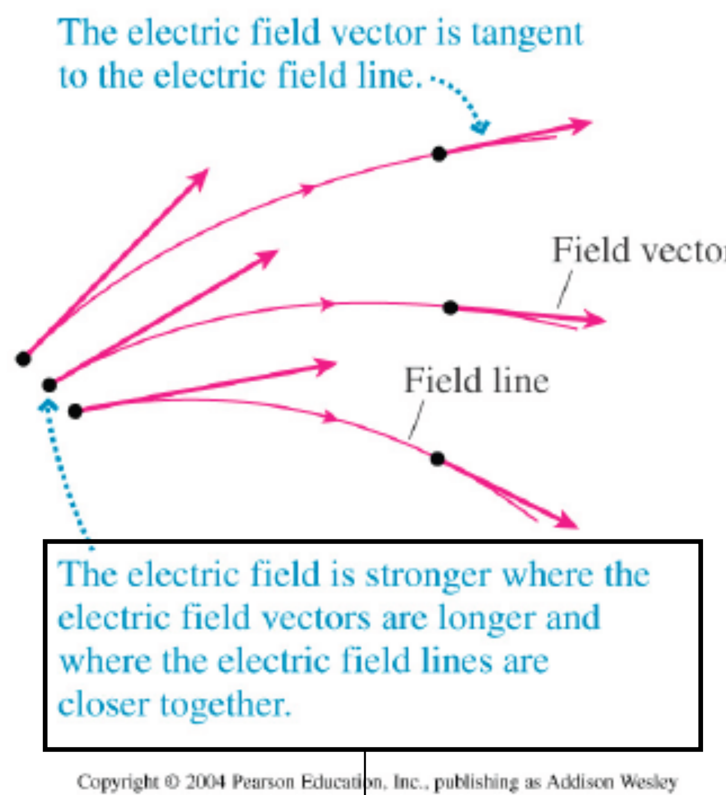




Concentric spheres

Electric field lines: review

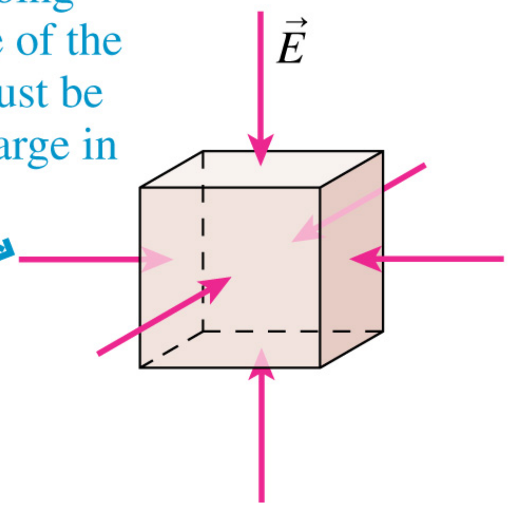
- Can draw electric field vectors at various points in space
- Or draw electric field lines; imaginary lines drawn through a region of space such that
    - tangent to a field line at any point in space is in the direction of the E field at that point
    - field lines are closer together where E field strength is larger
    - every field line starts on a positive charge and ends on a negative charge
    - field lines cannot cross



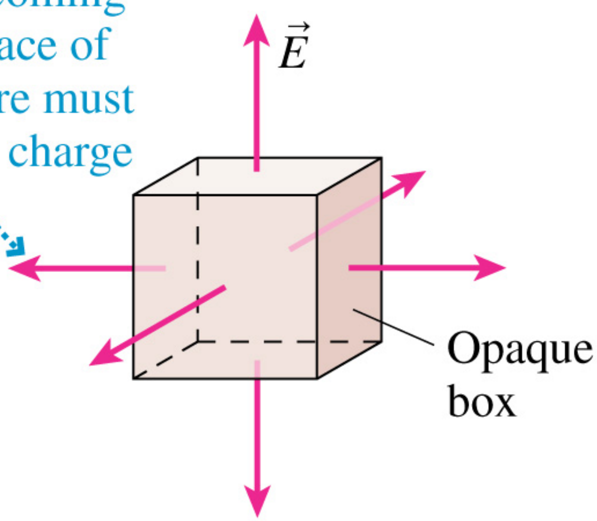
…the larger the charge the more field lines I should draw coming from (or going into) the charge

Electric flux

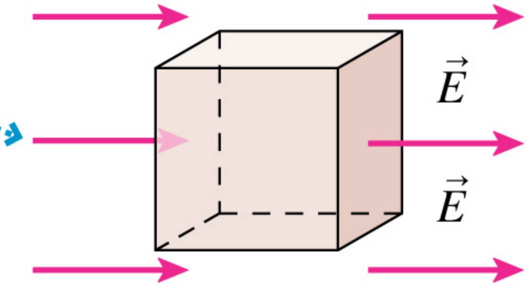
- I can think of the electric flux as being the net number of electric field lines going into or coming out of a surface
  - outward flux around a + charge
  - inward flux around a - charge
  - no flux around region where there is no charge



(b) The field is going into each face of the box. There must be a negative charge in the box.



(a) The field is coming out of each face of the box. There must be a positive charge in the box.

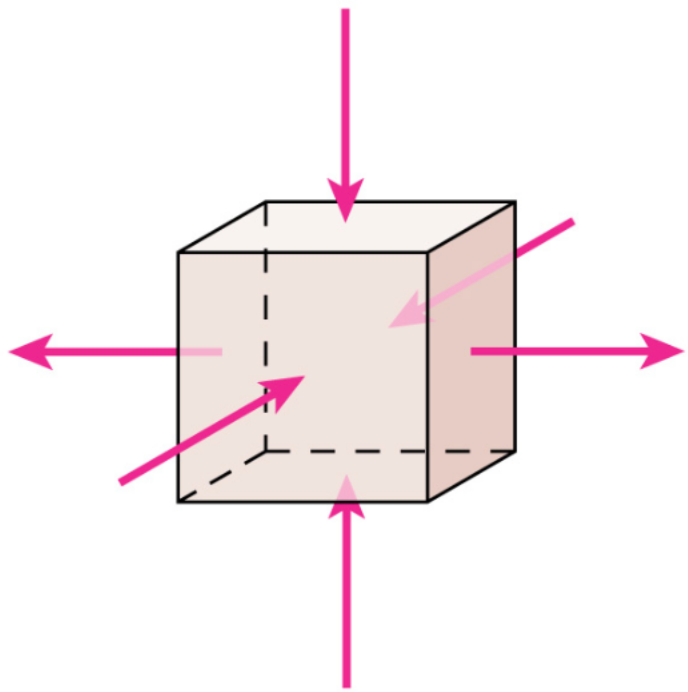


(c) A field passing through the box implies there's no net charge in the box.

iclicker question

This box contains...

A. a net positive charge.
B. a net negative charge.
C. a negative charge.
D. a positive charge.
E. no net charge.



The arrows represent electric fields. The electric field for each face is uniform and the same magnitude.

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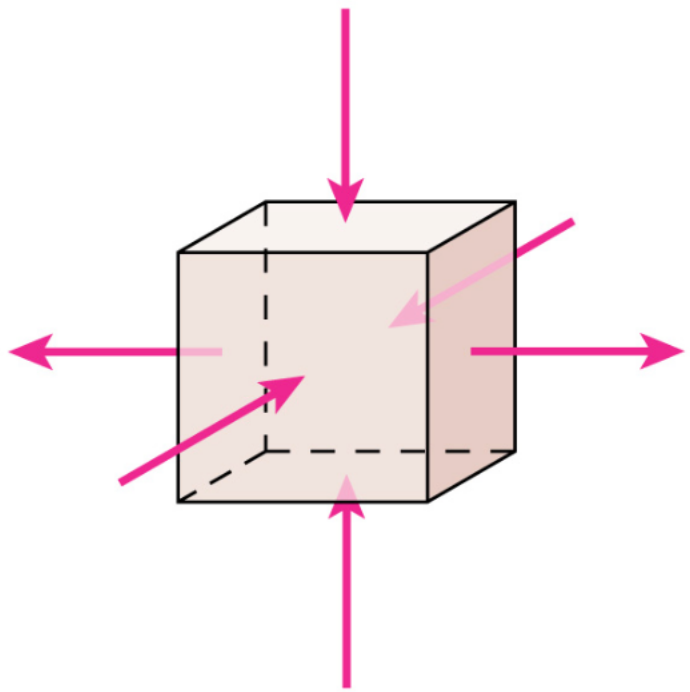

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iclicker question

The electric field is constant over each face of the cube shown. What type of charge is contained in the box?

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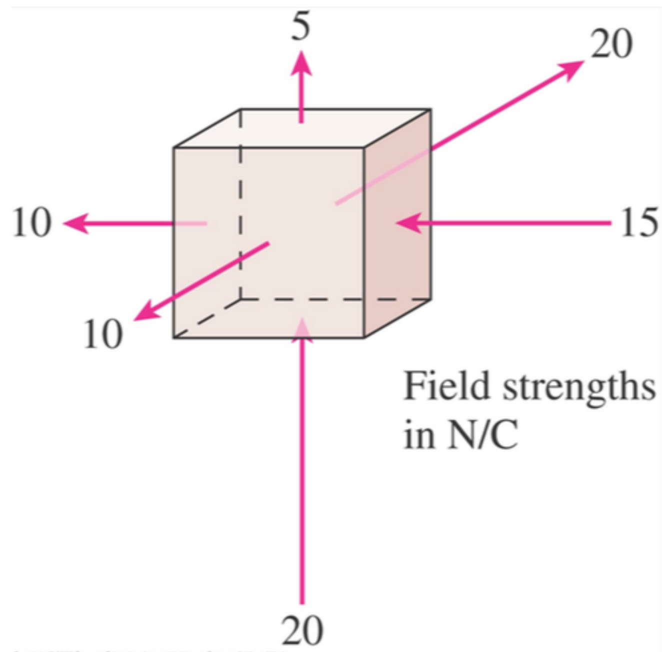

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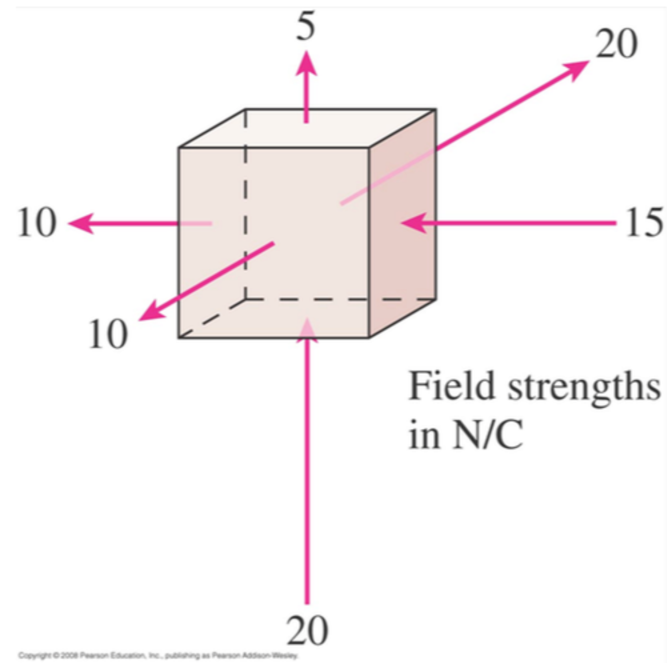
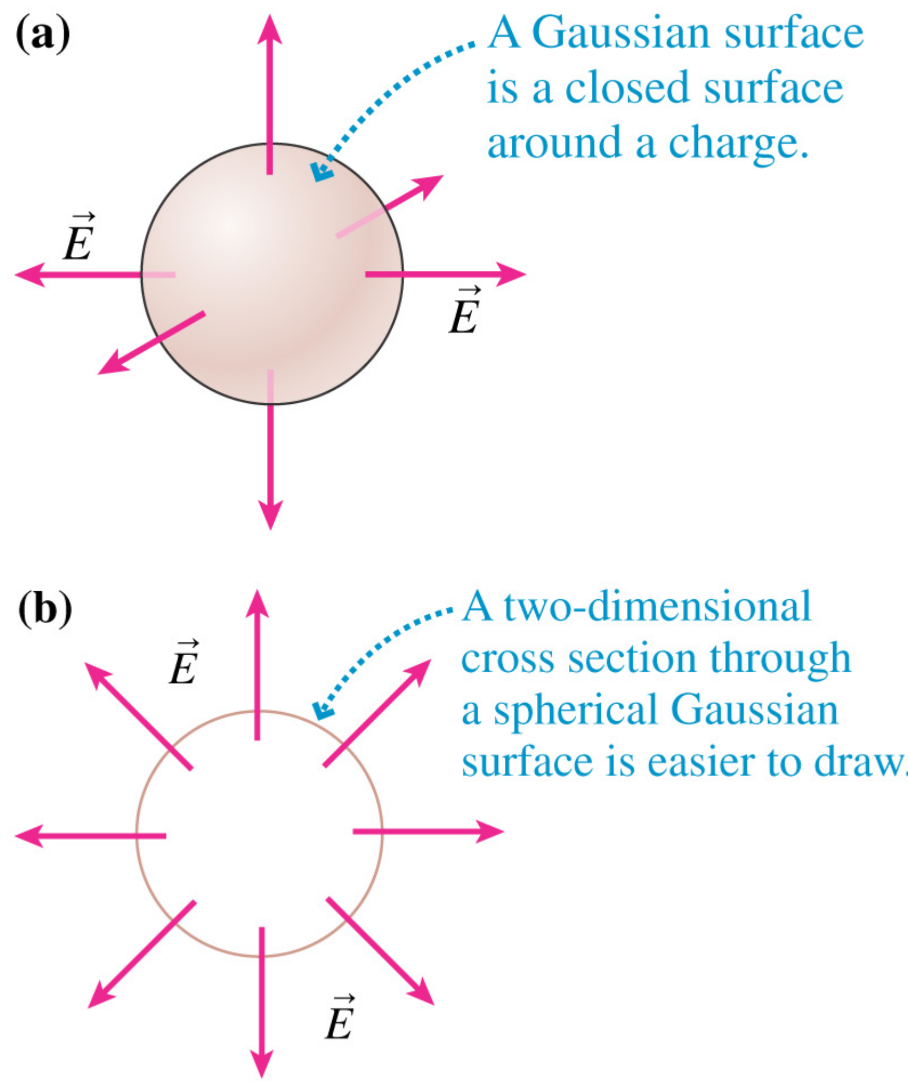


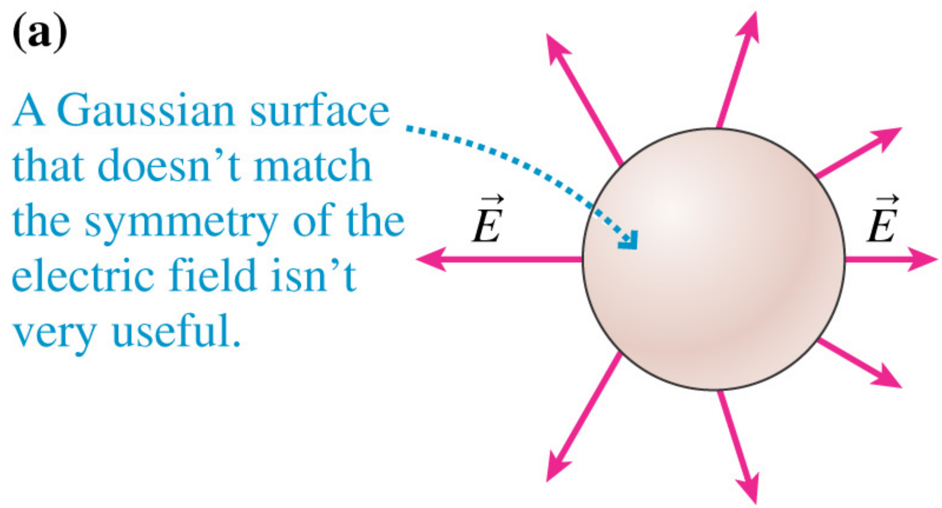
Gaussian surfaces

- I call a completely enclosed surface a Gaussian surface
- To be completely enclosed it of course has to be 3-dimensional but will most often be represented by a 2-D projection



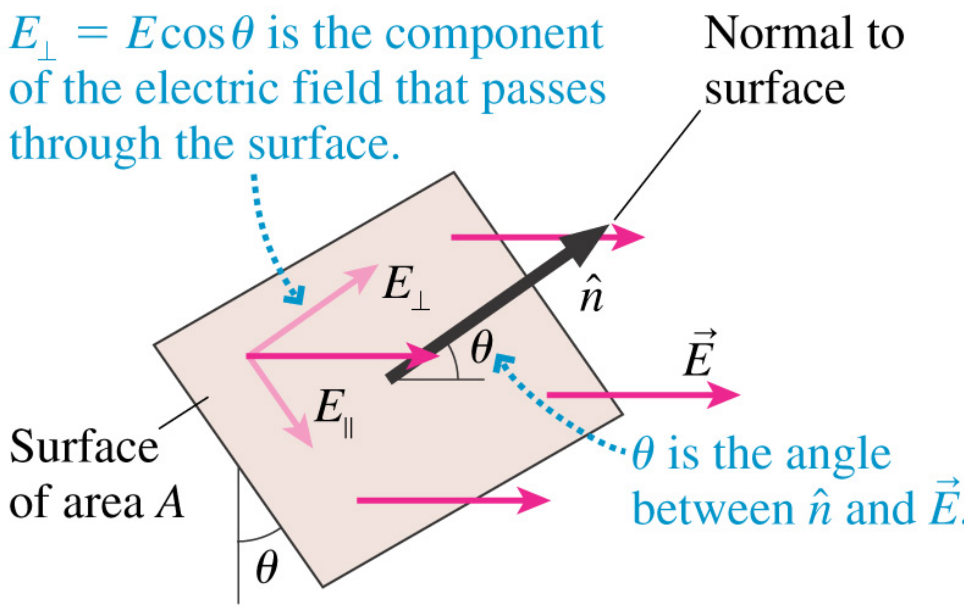
Gaussian surfaces

- Usually we try to pick the Gaussian surfaces to match the observed symmetry of the charge distributions…and always a closed surface



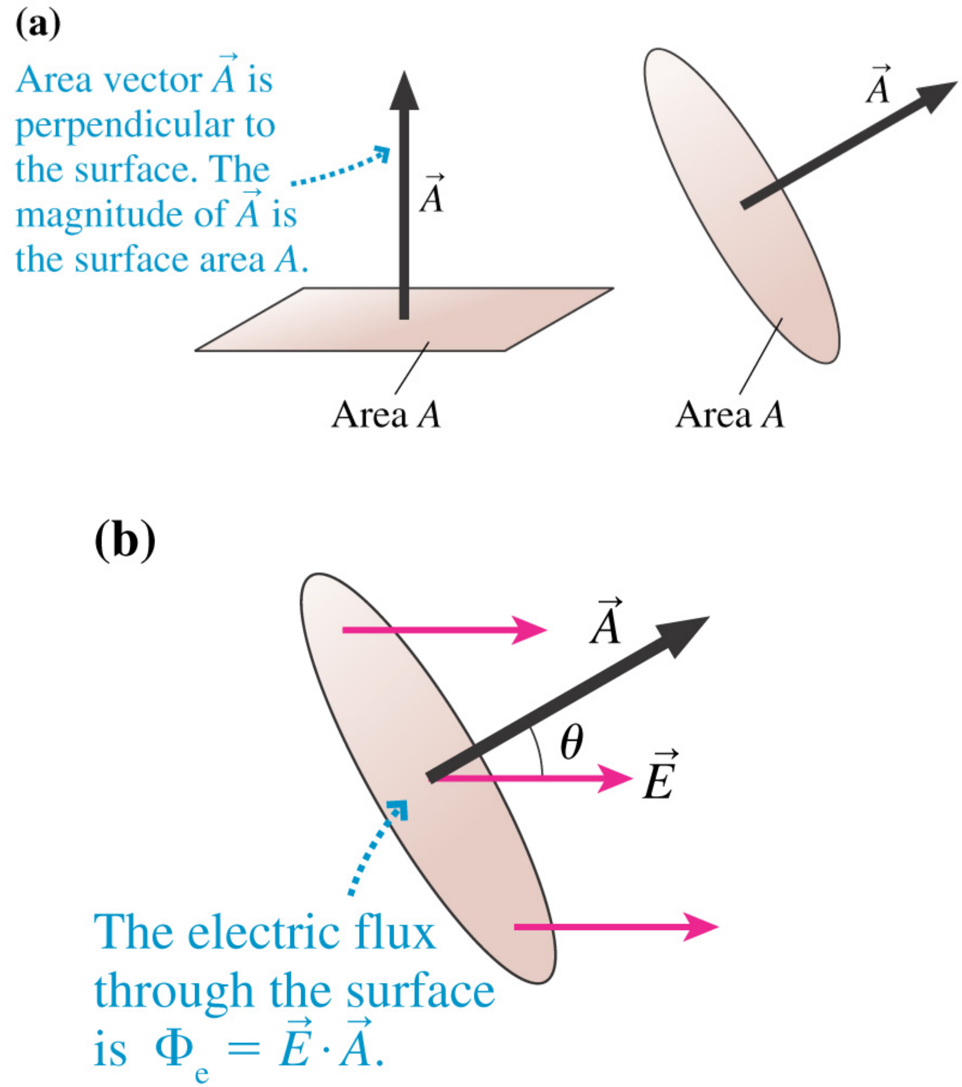
Electric flux

- Let's define now the electric flux through a surface (for the moment not necessarily a closed surface)
  - $\Phi = E_T A = EA \cos\theta$
  - where θ is the angle between the normal to a surface at a particular point and the electric field passing through that point on the surface
- The electric flux measures the amount of electric field passing through a surface A if the normal to A is tilted an angle θ with respect to the electric field
  - or as I like to visualize it, the number of electric field lines



Electric flux

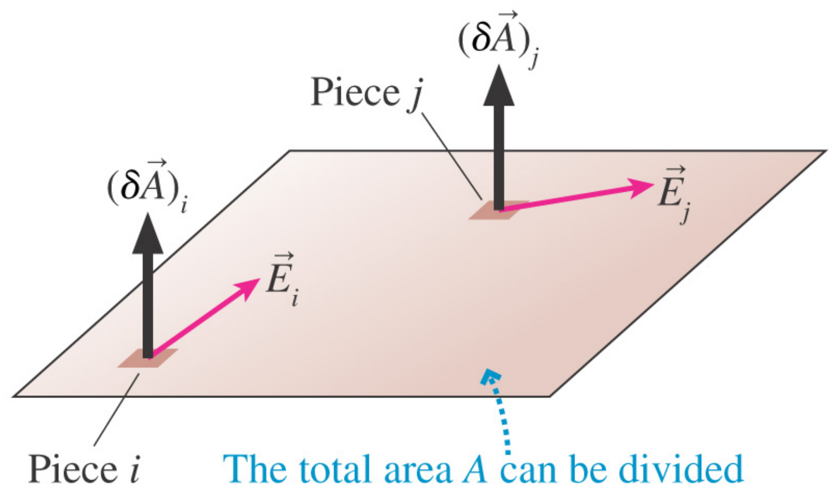
- Let's define a vector $\vec{A} = A\hat{n}$ to be a vector in the direction of $\hat{n}$ but with the magnitude of the area of the surface
- Why would we want to do this?
- So we can come up with a shorter notation for the electric flux
  - $\Phi = \vec{E}\cdot\vec{A} = EA\cos\theta$
  - The electric flux is the scalar product of the electric field and the vector $\vec{A}$

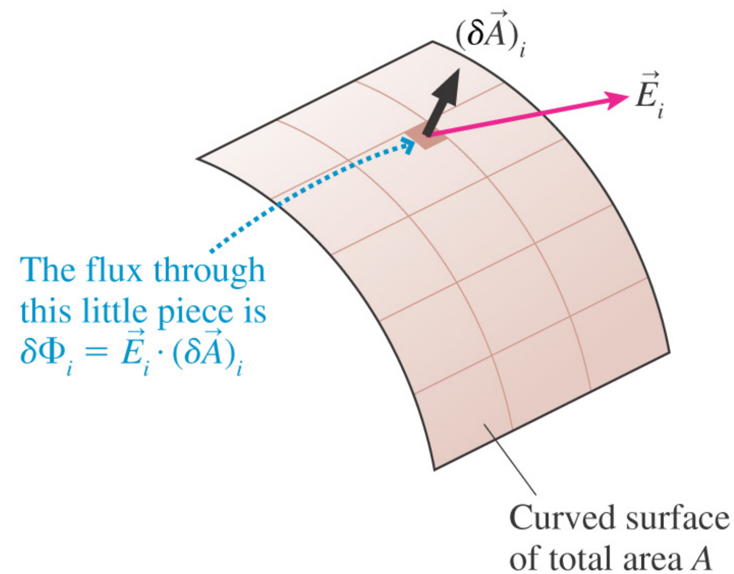


Electric flux

- If the electric field is non-uniform, or if the surface is non-uniform, then I can calculate the electric flux from each little piece where I can approximate things as being uniform and then add all of these pieces together
  - $\delta\Phi_i = \vec{E}_i \cdot (\delta\vec{A})_i$
  - $\Phi_e = \Sigma\delta\Phi_i = \Sigma\vec{E}_i \cdot (\delta\vec{A})_i$

$$\Phi_e = \int_{\text{surface}} \vec{E} \cdot d\vec{A}$$



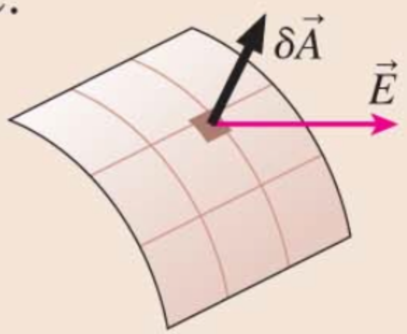


Quick review

Surface integrals calculate the flux by summing the fluxes through many small pieces of the surface:

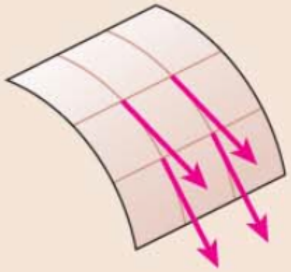
$$\Phi_e = \sum \vec{E} \cdot \delta\vec{A}$$

$$\rightarrow \int \vec{E} \cdot d\vec{A}$$



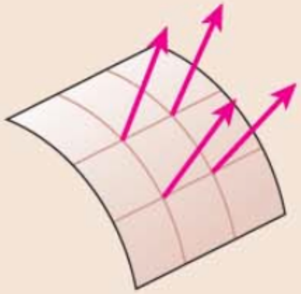
Two important situations:
If the electric field is everywhere tangent to the surface, then

$$\Phi_e = 0$$



If the electric field is everywhere perpendicular to the surface *and* has the same strength E at all points, then

$$\Phi_e = EA$$

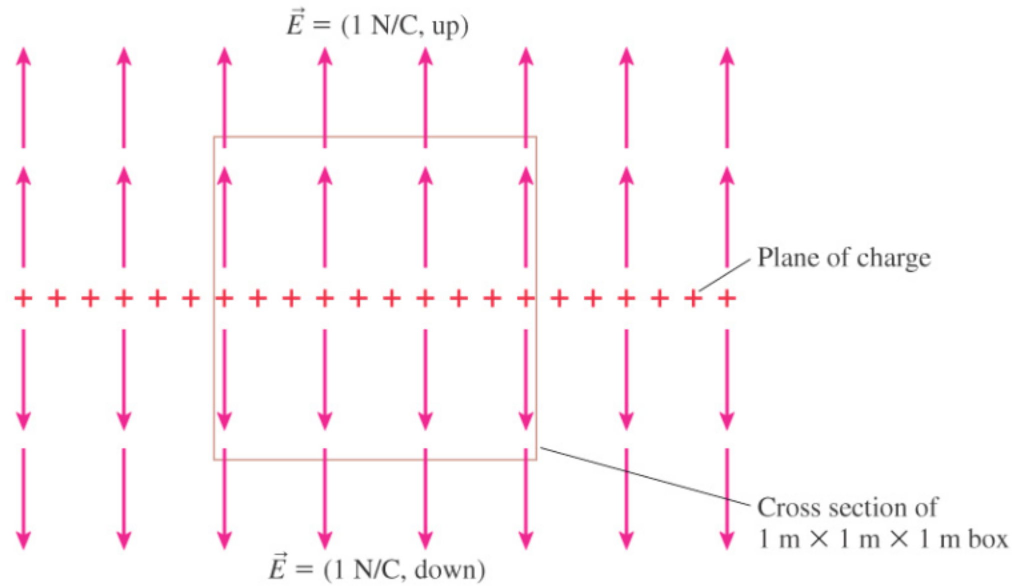


iclicker question

The total electric flux through this box is…

$$\Phi_e = EA\cos\theta = \vec{E}\cdot\vec{A}$$

A. 6 Nm^2/C
B. 4 Nm^2/C
C. 2 Nm^2/C
D. 1 Nm^2/C
E. 0 Nm^2/C



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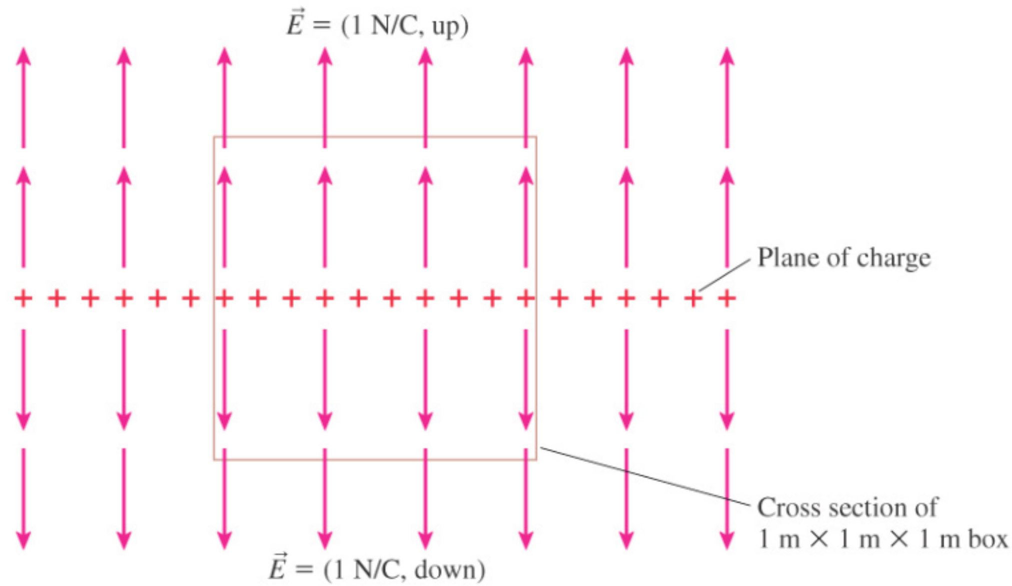
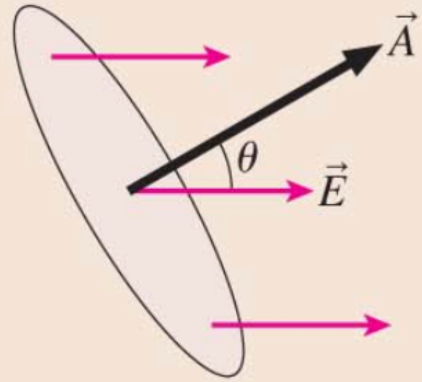


Quick review

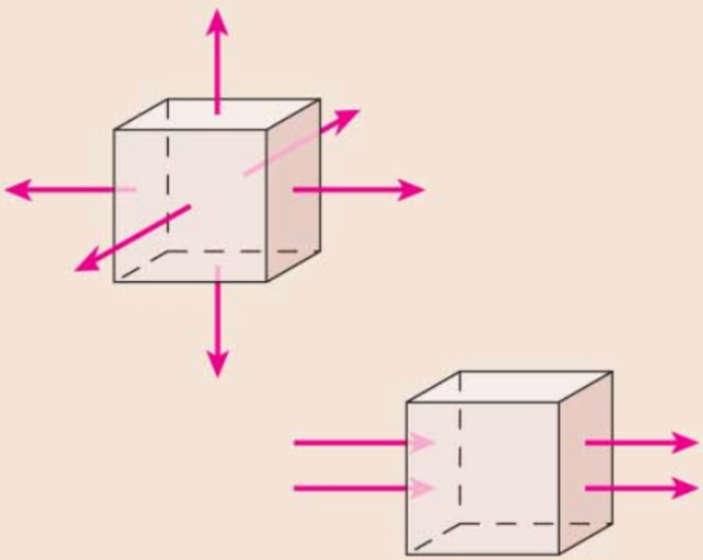
Flux is the amount of electric field passing through a surface of area A:

$$\Phi_e = \vec{E} \cdot \vec{A}$$

where $\vec{A}$ is the **area vector.**

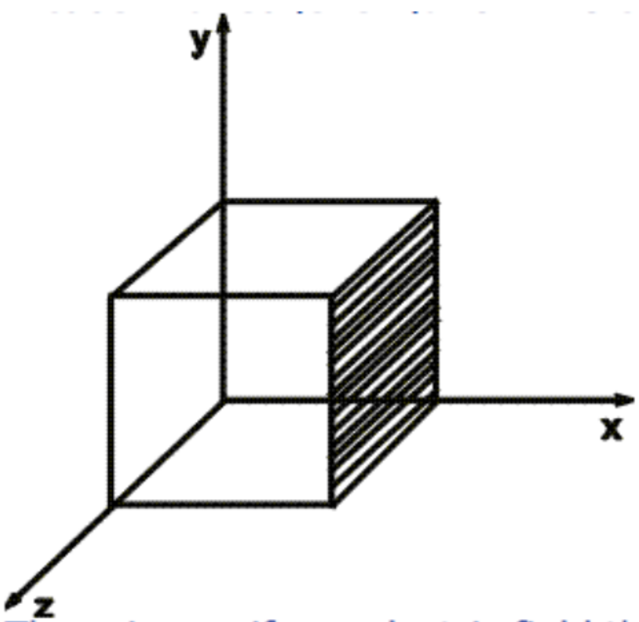


For closed surfaces:
A net flux in or out indicates that the surface encloses a net charge. Field lines through but with no *net* flux mean that the surface encloses no *net* charge.



Example

A cube with edge length of l = 42 cm is positioned as in the figure. There is a uniform electric field throughout the region given by E = 5.1**i** +7.9**j** +4.8**k** in N/C units, but there is no charge within the cube. What is the magnitude of the **total flux through the five non-shaded faces**?



$$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\varepsilon_0}$$

There is NO charge within the cube so Q_{in} = 0 and hence the total flux must also be 0 (Φ_{tot} = 0) but you are asked for the **magnitude** of the flux through 5 sides (excluding the shaded side).

$$\Phi_{tot} = \Phi_{shaded} + \Phi_{unshaded} = 0$$

$$|\Phi_{unshaded}| = |-\Phi_{shaded}|$$

Example

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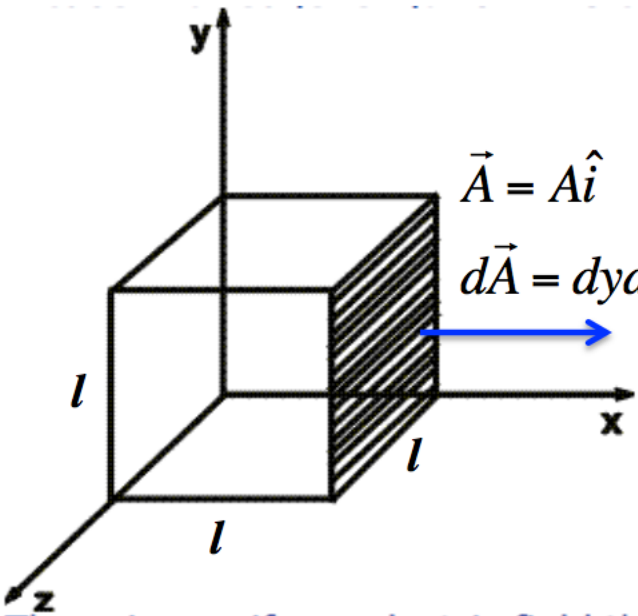


$$\vec{A} = A\hat{i}$$

$$d\vec{A} = dydz\hat{i}$$

$$|\Phi_{unshaded}| = |-\Phi_{shaded}|$$

$$\Phi_{shaded} = \oint \vec{E} \bullet d\vec{A}$$

$$\Phi_{shaded} = \oint (5.1\hat{i} + 7.9\hat{j} + 4.8\hat{k}) \bullet dy\,dz\hat{i}$$

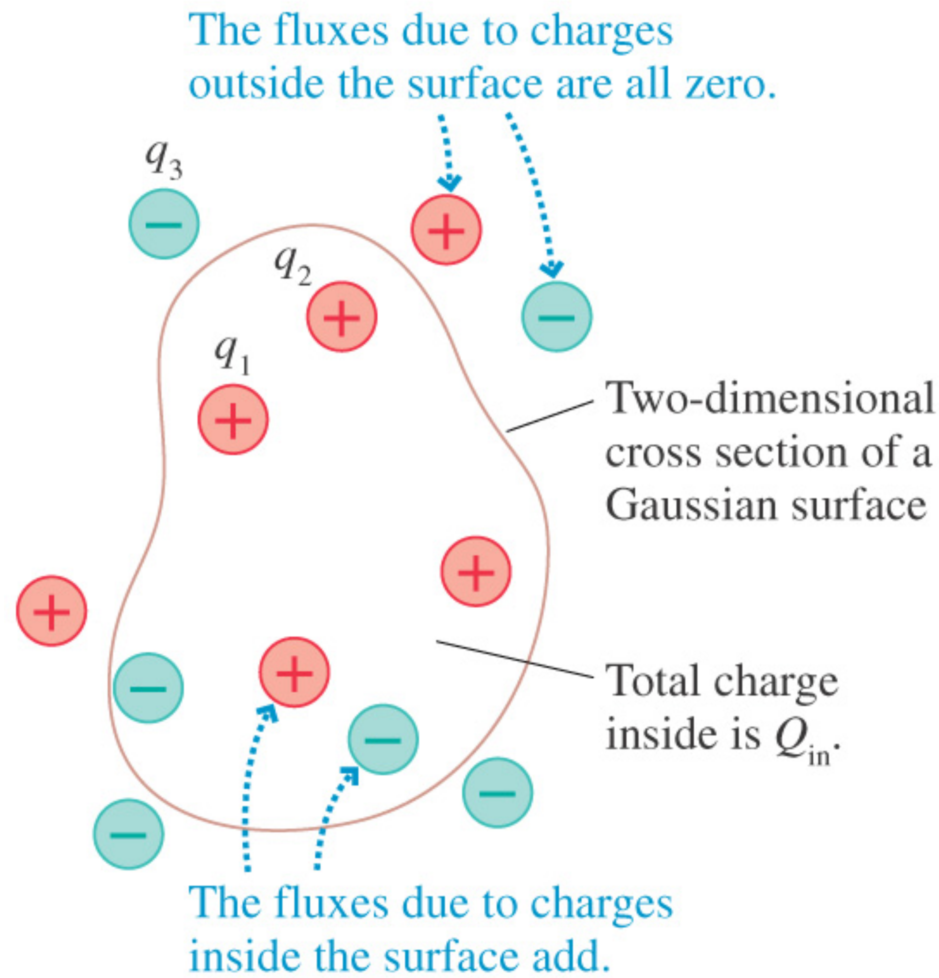
Remember: $\hat{i} \bullet \hat{j} = \hat{i} \bullet \hat{k} = \hat{j} \bullet \hat{k} = 0$ and

$$\hat{i} \bullet \hat{i} = \hat{j} \bullet \hat{j} = \hat{k} \bullet \hat{k} = 1$$

$$\Phi_{shaded} = \int_0^l \int_0^l 5.1\,dy\,dz = 5.1l^2 = 0.90 \text{ N m}^2 / C$$

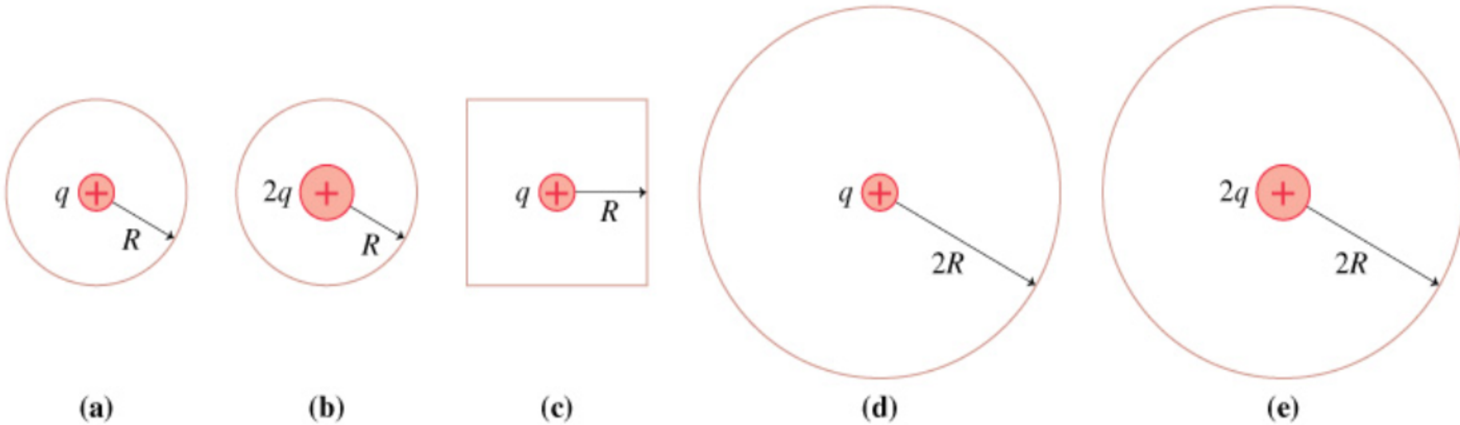
Multiple charges

- Only the charges inside contribute to the flux
- I can calculate the flux not by doing a (very complicated, most likely) integral, but by adding the up the total charge inside the Gaussian surface



iclicker question

These are 2D cross sections through 3D closed surfaces. Rank order, from largest to smallest, the electric fluxes Φ_a to Φ_e through surfaces a to e.



A. $\Phi_a > \Phi_c > \Phi_b > \Phi_d > \Phi_e$
B. $\Phi_b = \Phi_e > \Phi_a = \Phi_c = \Phi_d$
C. $\Phi_e > \Phi_d > \Phi_b > \Phi_c > \Phi_a$
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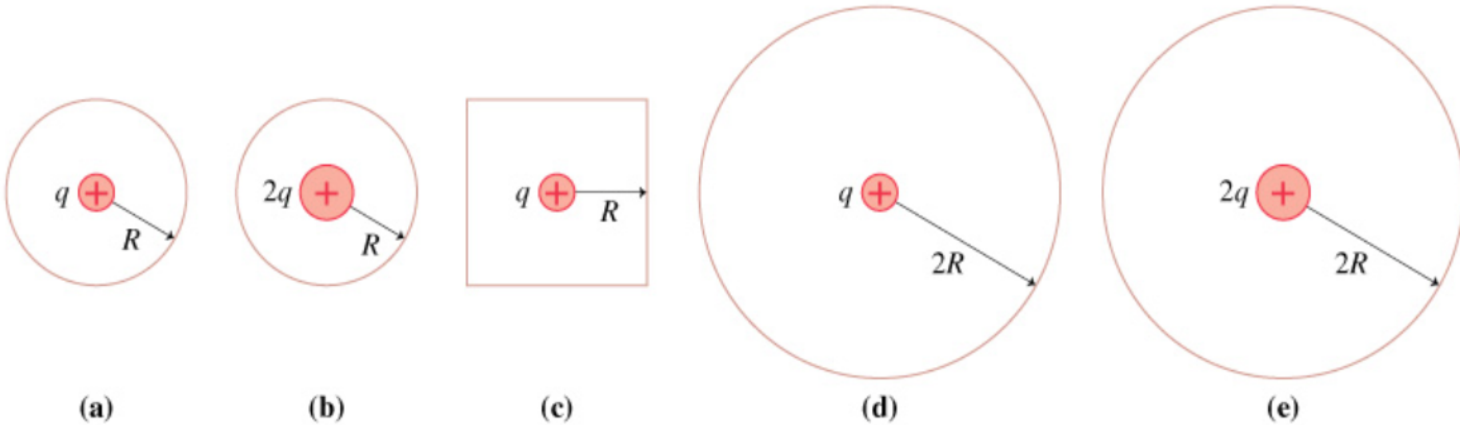

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Gauss' law

- Caveats
  - Gauss' law applies only to a closed surface
  - Gaussian surface is not a physical surface, just a mathmatical construct
  - can't find the electric field from Gauss' law alone; need to apply it in situations where we can already guess at the shape of the field
- Let's start with the field outside of a spherical charge distribution