Last time

- Tophat questions
- More on electric field vectors and lines for a point charge
- Electric field vectors and lines for a dipole
- Electric field vectors and lines for two like charges
- General properties of electric field lines

This time

- Force on a point charge in an external electric field
- Calculation of electric flux
- Example

Force on a point charge in an external electric field

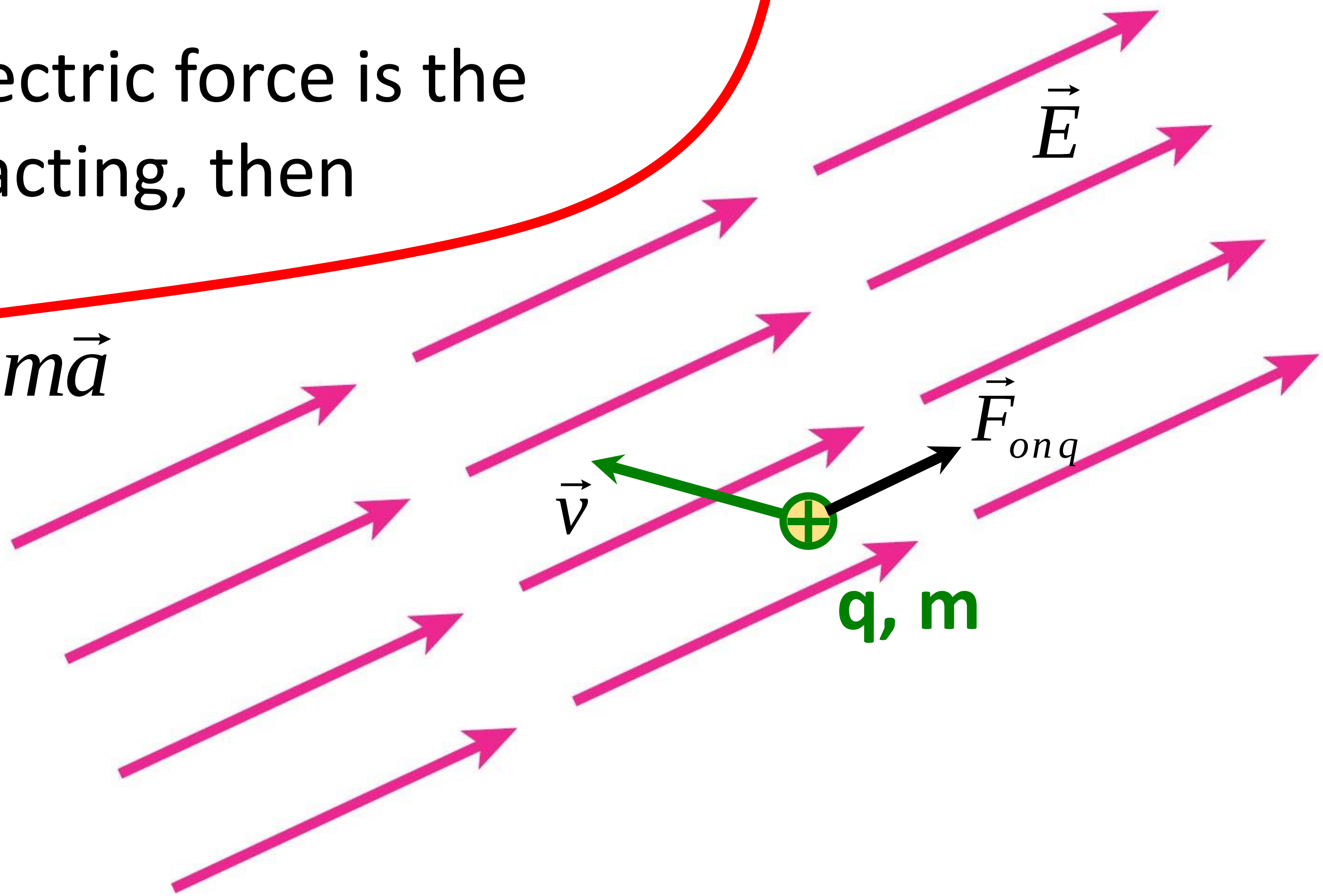
Electric force on q: $\vec{F}_{on\,q} = q\vec{E}$

Newton's 2nd Law: $\vec{F} = m\vec{a}$

So if the electric force is the only force acting, then

$$\vec{F}_{on\,q} = m\vec{a}$$

$$q\vec{E} = m\vec{a}$$



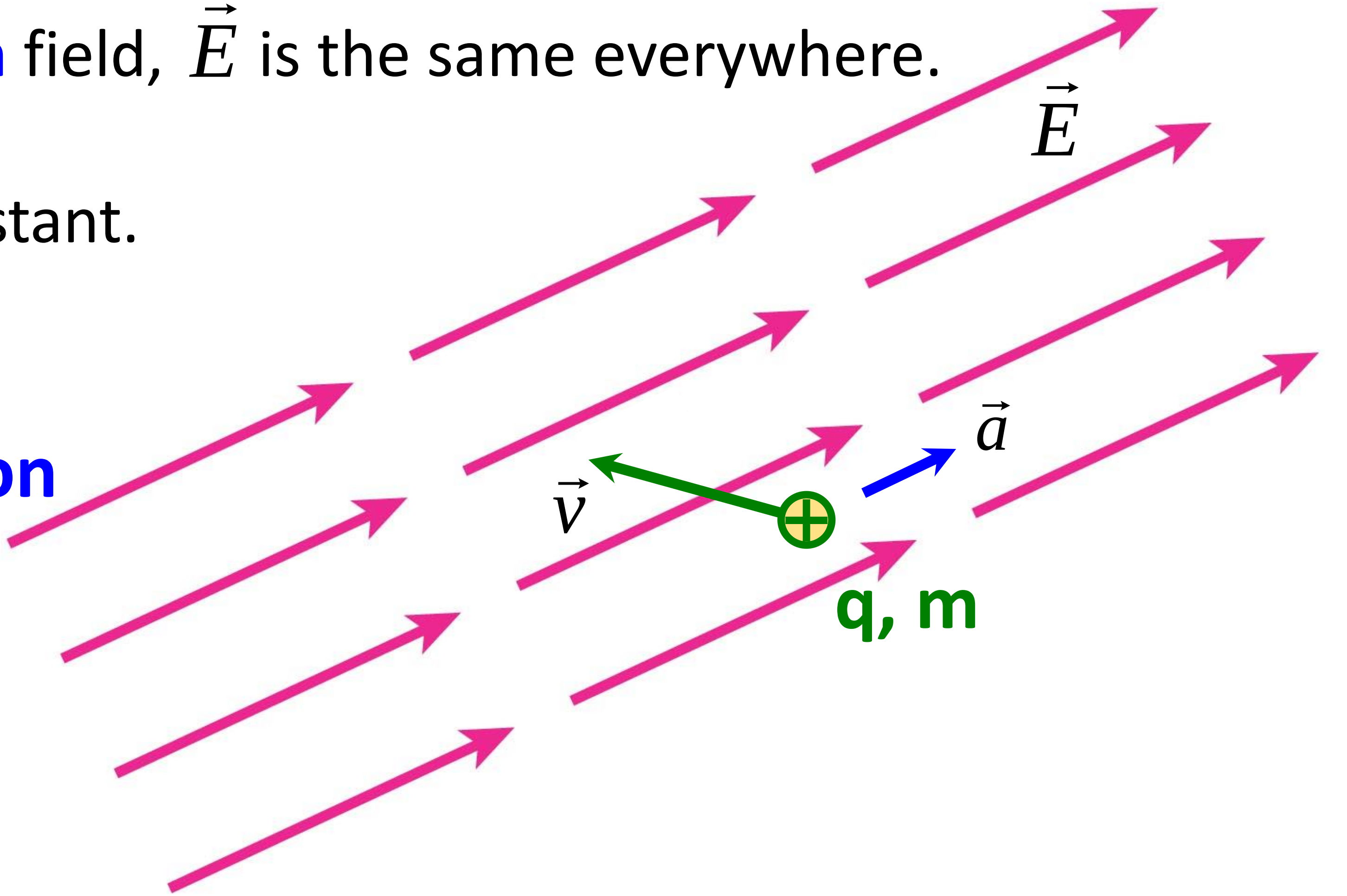
$$q\vec{E} = m\vec{a} \quad \Rightarrow \quad \boxed{\vec{a} = \frac{q\vec{E}}{m}}$$

q = constant
m = constant

In a **uniform** field, $\vec{E}$ is the same everywhere.

So $\vec{a}$ is constant.

Constant acceleration motion!



Uniform E-field: projectile motion

$$\vec{F}_{net} = q\vec{E}$$

Take E to point along +x-direction

$$a_x = \frac{qE}{m}$$

If q is +, a_x is +
If q is −, a_x is −

$$a_y = 0$$

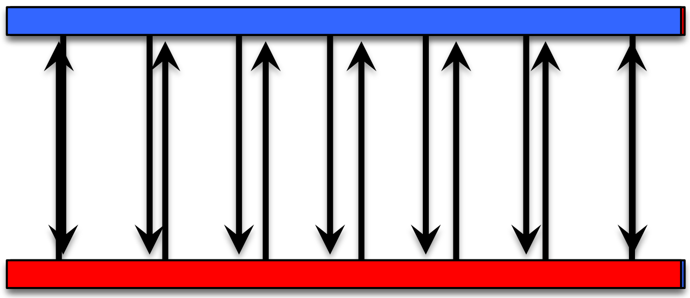
$$x_f = x_i + v_{ix}\Delta t + \frac{1}{2}\frac{qE}{m}\Delta t^2$$

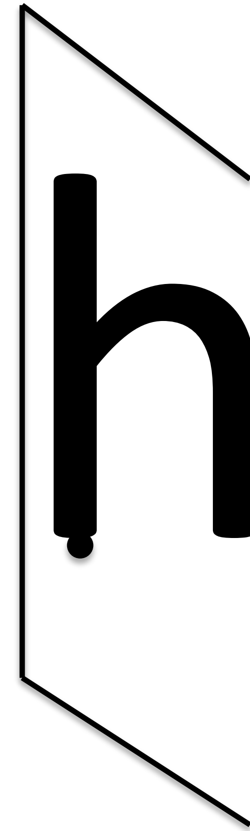
$$y_f = y_i + v_{iy}\Delta t$$

$$v_{fx} = v_{ix} + \frac{qE}{m}\Delta t$$

$$v_{fy} = v_{iy}$$

Application: Inkjet Printers





By controlling the strength of the electric field between the plates, you control the deflection of the charged ink droplets. This allows you to feed an electronic signal to the plates, thereby allowing you to create images out of ink droplets (in this case, letters)

Application: Inkjet Printers

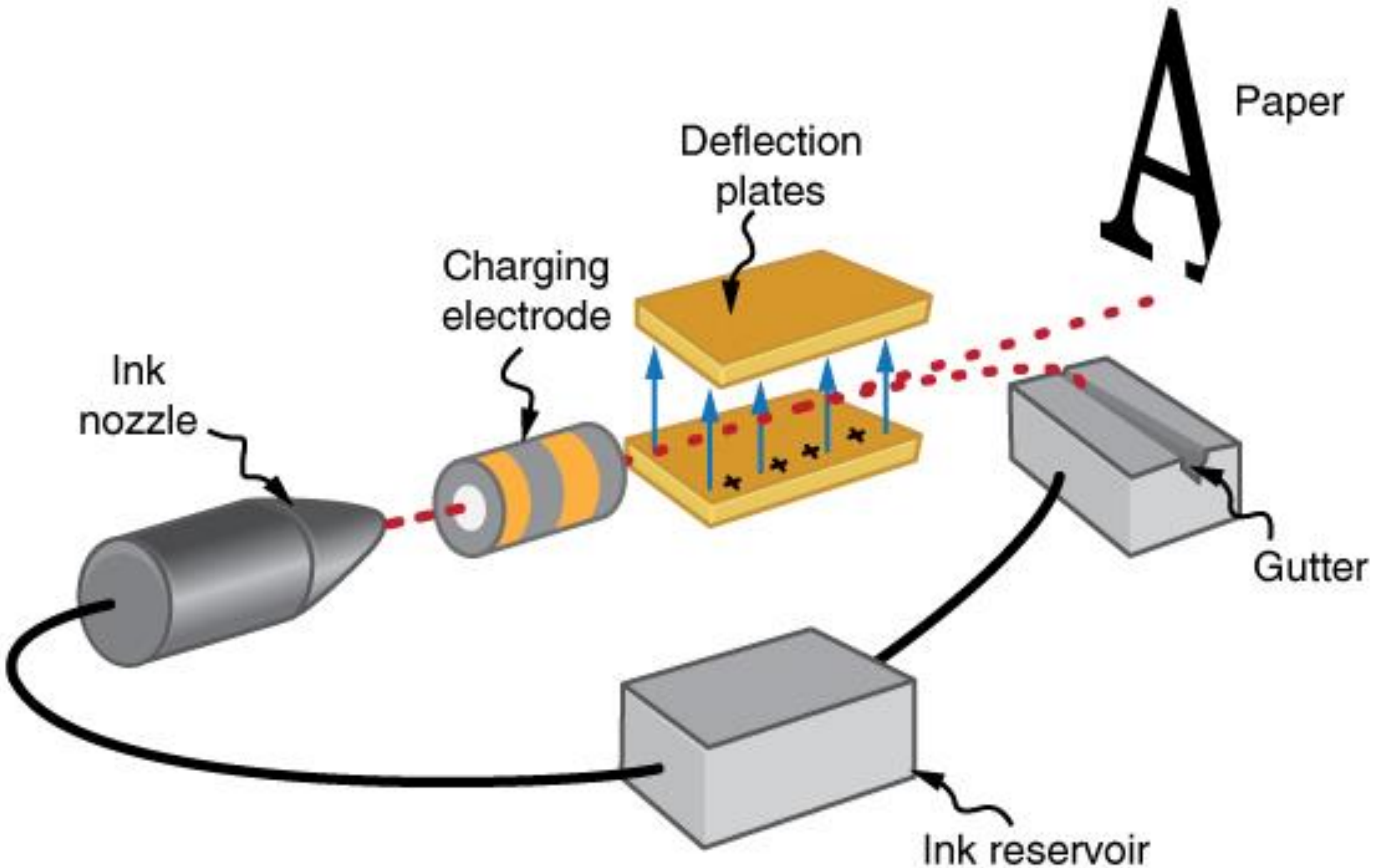


Image from https://courses.candelalearning.com/colphysics/chapter/18-8-applications-of-electrostatics/

Carl Friedrich Gauss (1777-1855) Germany

He started elementary school at the age of seven.

His teacher was amazed when Gauss summed the integers from 1 to 100 instantly.

At the age of 21, he constructed a regular 17-gon by ruler and compasses. This was the most major advance in this field since the time of Greek mathematics.

Gauss and Weber discovered Kirchhoff's laws, as well as building a primitive telegraph device which could send messages over a distance of 5000 ft.

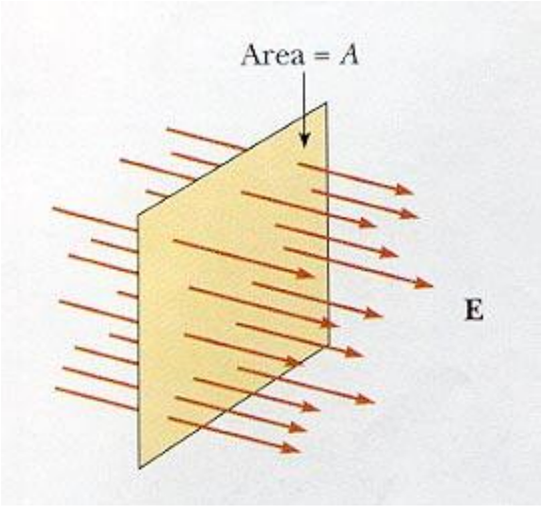
Calculation of flux

Flux is measured as the number of electric field lines crossing a surface.

Simplest case!

1. Electric field is uniform. Electric filed lines are straight lines, parallel to each other and have uniform density.

2. The surface is flat and perpendicular to the electric field lines.



$$\Phi_E = EA$$

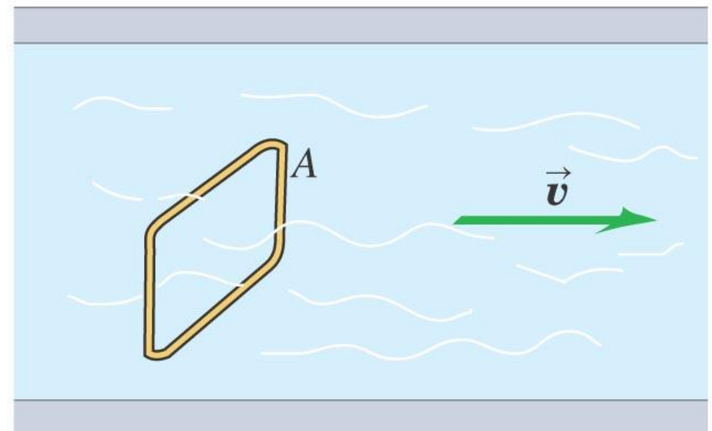
Special case!!!!!

Flux is a scalar quantity!

Calculating flux

Stream of air with velocity $\vec{v}$ Moving perpendicular to the rectangle. In this case rectangle represents the volume flow rate (the volume of fluid crossing the surface per unit time).

(a) A wire rectangle in a fluid

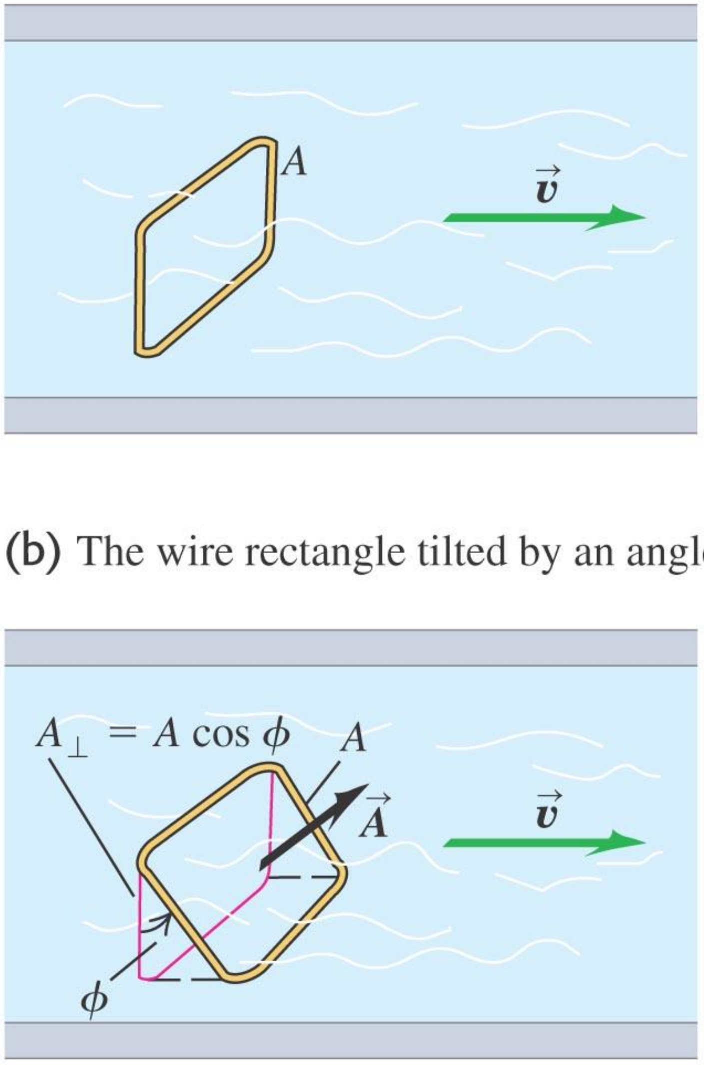


Calculating flux

– If we considered flux through a rectangle, the flux will change as the rectangle changes orientation to the flow.

(a) A wire rectangle in a fluid

(b) The wire rectangle tilted by an angle ϕ



How do we calculate flux?

1. Electric field is uniform.

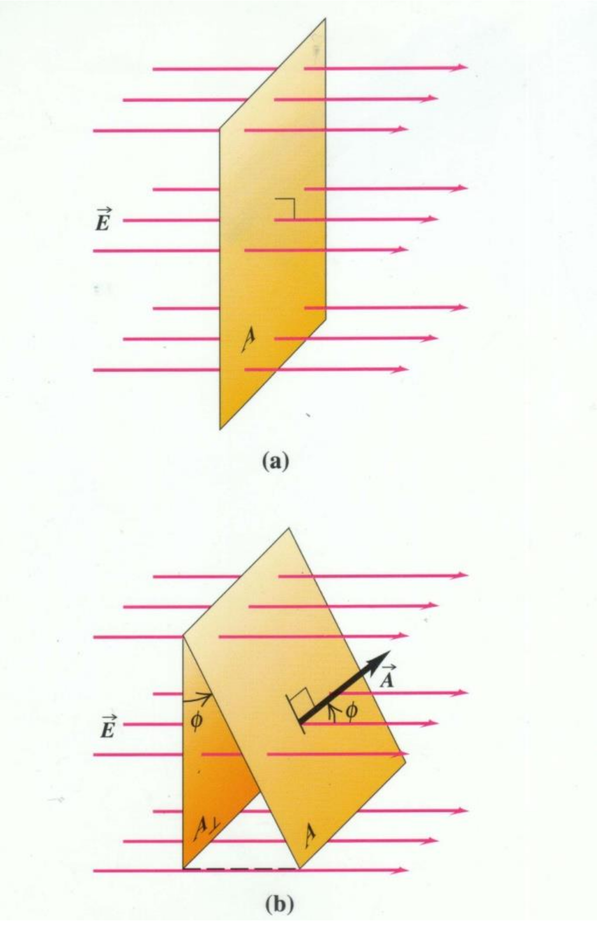
2. The surface is flat but has an angle ϕ with the electric field lines.

Project the plane in the direction which is perpendicular to the electric field.

Use this projected surface as the effective surface and calculate the flux as before.

$$A_{\perp} = A\cos\phi$$

Projection perpendicular to $\vec{E}$



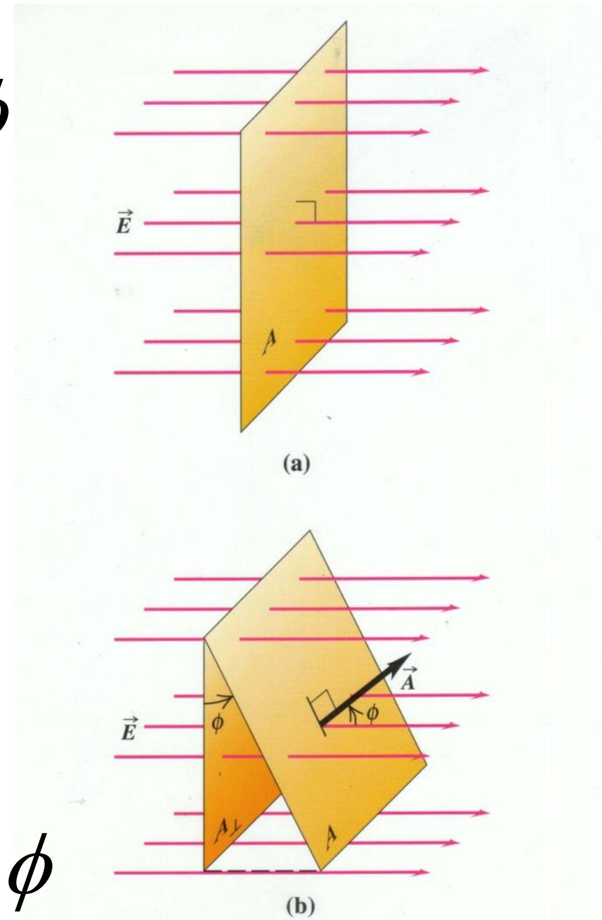
$$\Phi_E = EA_{\perp} = E\left(A\cos\phi\right) = EA\cos\phi$$

$$\Phi_E = \vec{E} \bullet \vec{A}$$

$$A_\perp = A\cos\phi$$

Projection perpendicular to $\vec{E}$

$$\Phi_E = EA_\perp = E\left(A\cos\phi\right) = EA\cos\phi$$



$$\Phi_E = \vec{E}\bullet\vec{A}$$

$$E_\perp = E\cos\phi$$

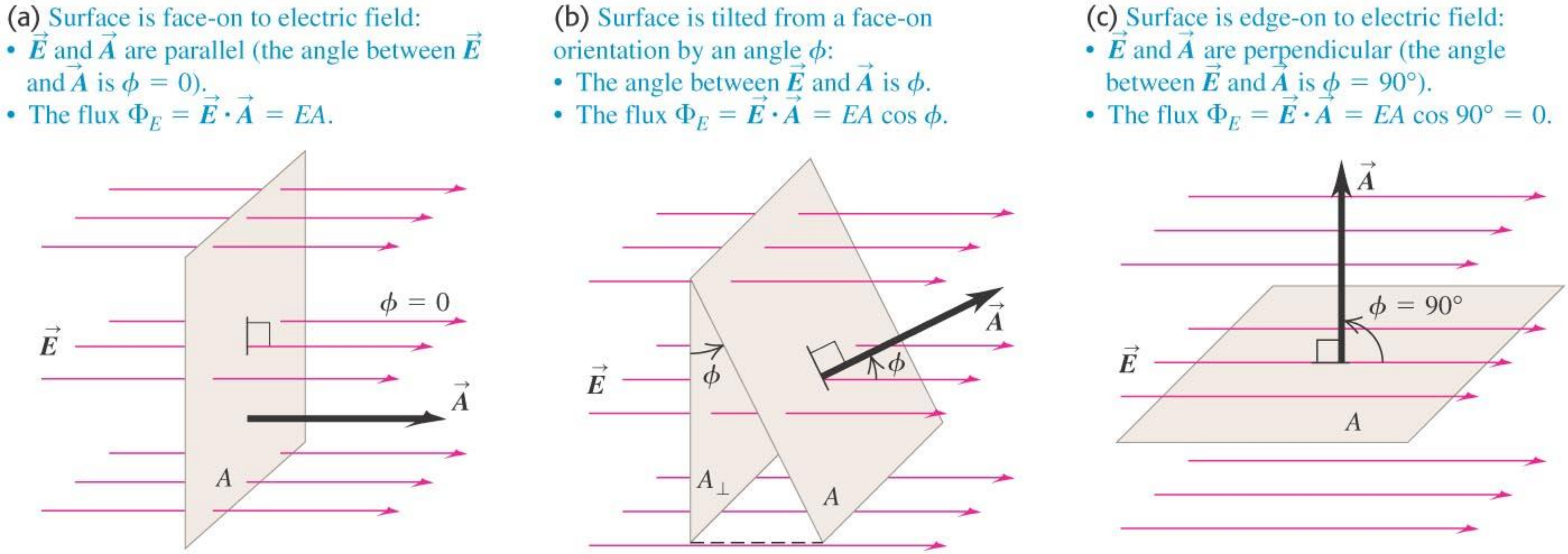
Projection of $\vec{E}$ perpendicular to $\vec{A}$

$$\Phi_E = E_\perp A = \left(E\cos\phi\right)A = EA\cos\phi$$

When do we have maximum and minimum flux?

Flux in a uniform field

- Measurement of the flux for a uniform electric field

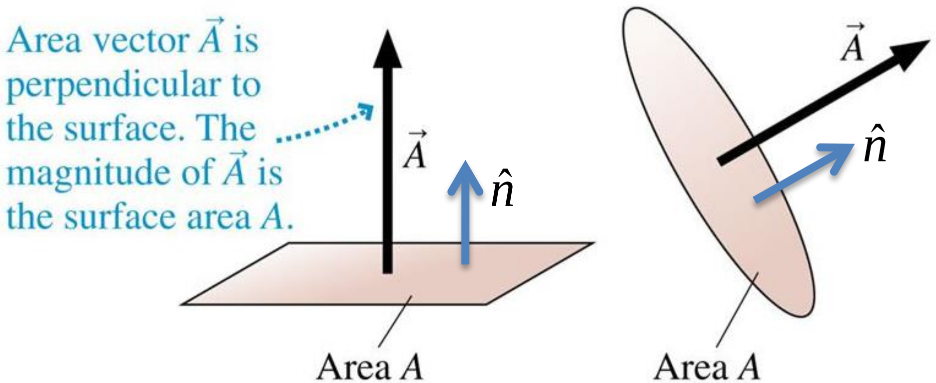


Maximum flux Intermediate flux Zero flux

$$\Phi_E = EA\cos\phi = \vec{E} \bullet \vec{A}$$

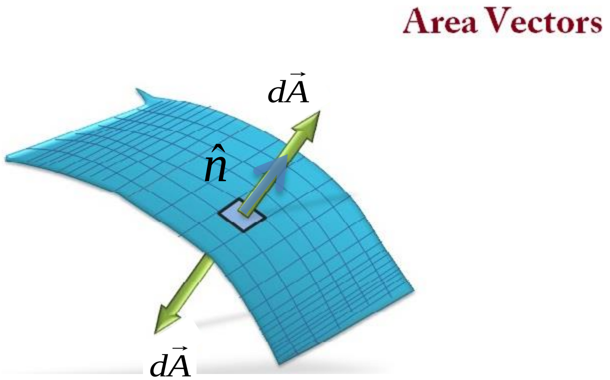
How do we define the area vector?

Flat open surface



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

Arbitrary open surface



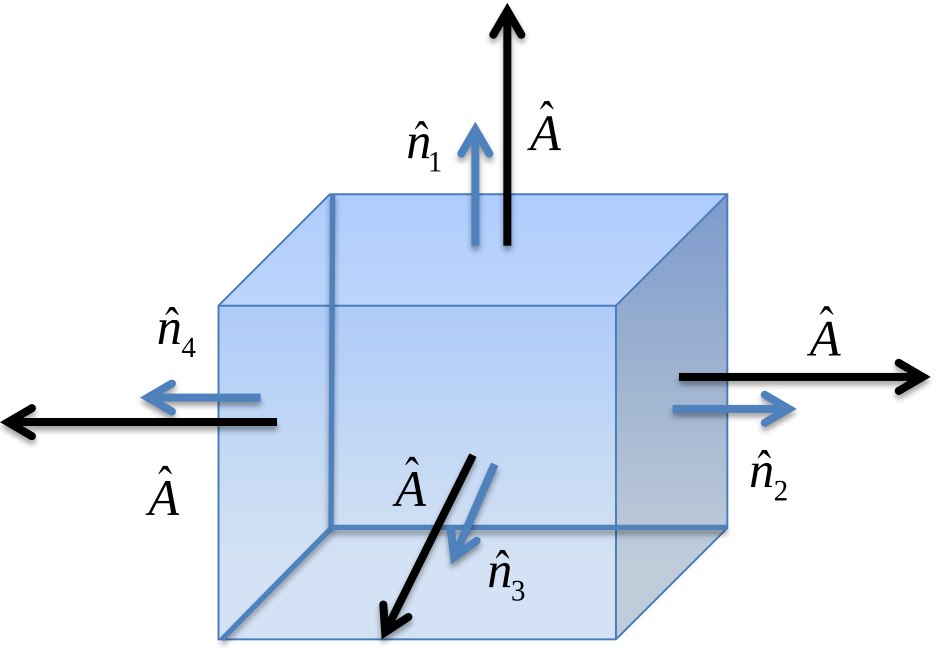
$$d\vec{A} = dA\hat{n}$$

Note that the area vector could also be drawn on the opposite side of the surface.

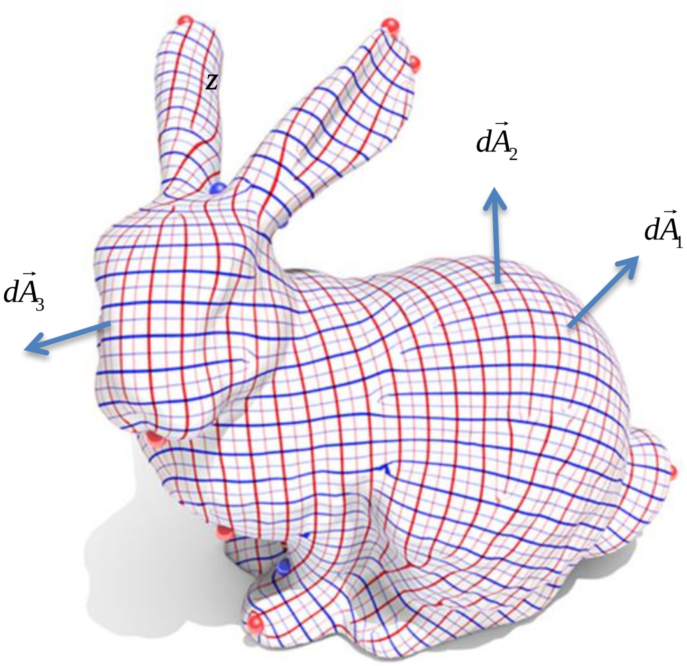
An open surface doesn't define a volume.

How do we define the area vector?

Flat closed surface



Arbitrary closed surface



A closed surface defines a volume.

Flux for a flat surface and uniform electric field

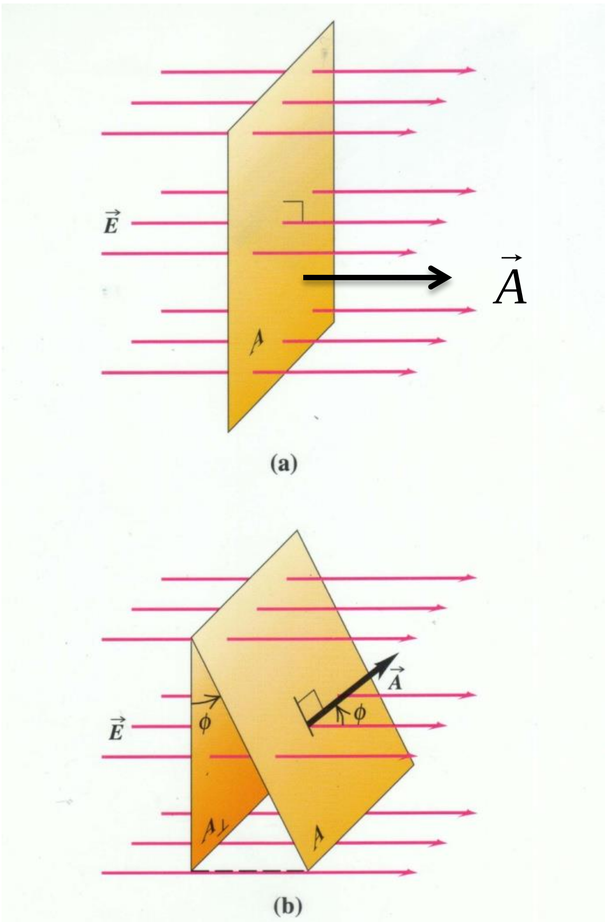
$$\Phi_E = \vec{E} \bullet \vec{A}$$

(a)

$$\Phi_E = EA\cos 0 = EA$$

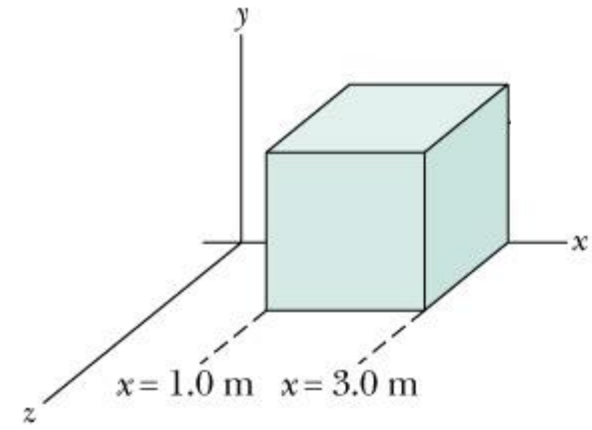
(b)

$$\Phi_E = \vec{E} \bullet \vec{A} = EA\cos\phi$$



Dot or scalar product of two vectors.

Example: Calculate the flux for the electric field expression and the closed surface given bellow.



$$\vec{E} = (3\ \text{N/Cm})\,x\hat{i} + (4\ \text{N/C})\,\hat{j}$$