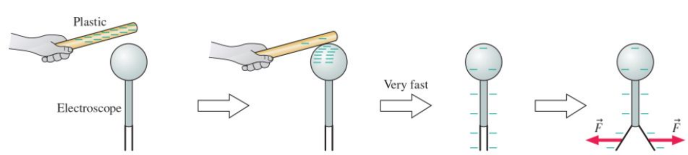
CH. 22: ELECTRIC CHARGES AND FORCES

- Charging = transfer of electrons from one object to another
    - Charging caused by frictional forces (e.g. rubbing)
    - Transfer of charge requires contact
    - Charged objects are attracted to any neutral object
        - Because of charge polarization (doesn't require touching) = temporary separation of positive and negative charges in a neutral object. Leads to net attractive polarization force.
    - Charged object picks up small pieces of paper (which is an insulator)
        - Because of electric dipole effect = formed by two opposite charges with a slight separation between them
            - Causes neutral atom to be polarized by and attracted toward an external charge.
        - Charged rod polarizes atoms in the paper and then exerts an attractive polarization force on each atom.
    - Charging by induction
        - Friction isn't the only way an object can become charged
        - Two sphere system:
            - Take two metal spheres and have them touch each other so they become a single conductor.
            - Take a negatively charged rod and place it near the spheres.
            - The electrons in closer sphere will be repelled by the rod and move to the further sphere (polarization as if the two-sphere were a single conductor). So now, the closer sphere is positively charged, while the further sphere is negatively charged.
            - We can separate the spheres and then remove the rod and the spheres will keep their (equal and opposite) respective charges.
    - Discharging
        - Touching a charged metal discharges it (two conductors in contact "share" the charge that was originally on just one of them).
        - Grounding objects (connected with earth) prevents build-up of charge
- Charge
    - Glass rod + silk = rod positively charged
    - Plastic rod + wool = rod negatively charged
    - Charge caused by excess/lack of electrons. Removing electron from atom is called ionization. Ions are created when bonds in a large molecule is broken during a process like rubbing.

The Sub-atomic Particles			
Relative size	Name	Mass (Kg)	Charge (C)
	Proton	1.67×10^{-27}	$+1.602 \times 10^{-19}$
	Neutron	1.67×10^{-27}	0
size exaggerated	Electron	9.11×10^{-31}	-1.602×10^{-19}

    - Electrons and protons governed by Newton's laws
    - Neutral object = no net charge
    - Charge is conserved.
- Conductors = charge moves easily (metal); Insulators = charge immobile (glass/plastic)
    - Both can be charged. Differ in the mobility of the charge.
    - Electrons in insulator tightly bound to the positive nuclei and can't move around. When insulator is charged, molecular ions are created but they can't move anywhere.
    - Conductors = sea of electrons around array of positively charged ion cores.
        - Electrons (charge carriers) can move around easily and create current.
        - Good conductors: metals and ionic solutions (like salt water)
    - Metals can't usually be charged by rubbing, but contact works. So charge transferred with touch and then repulsive forces between like charges causes very fast spreading of electrons.
    - This is also how metal electroscopes are charged:



    - Conductors are in electrostatic equilibrium = no net force on any charge.
        - Any excess charge is on surface of conductor
- Coulomb's Law
    - Quantitatively describes how electric force decreases with distance (inverse-square law)
    - **<u>Applies only to point charges</u>**
    - Input: two point charges
    - Output: electric force between them
    - $F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = k|q_1||q_2|/r^2$ → only gives magnitude!
        - Repulsive for two like charges, attractive for two opposite charges → gives direction of charge
        - $k = 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 = 1/(4\pi\varepsilon_0)$ where ε_0 = free space permittivity constant
    - Can be superimposed, so net electric force on charge j due to all others is:
        - $F_{net} = F_{1 \text{ on } j} + F_{2 \text{ on } j} + F_{3 \text{ on } j} + \ldots$

- Electric field
    - Explains how **long-range forces** (like electric/magnetic forces) are transmitted between charges
        - Charged particles interact via fields
    - In Faraday's view, particle A alters the space around it, then particle B responds to the altered space. This altered space is the agent that exerts the force on B. This altered space is a "field".
        - Fields exists simultaneously at all points in space.
    - Source charges create field E. A separate probe charge q in E experiences force $F = qE$ exerted by the field. Positive charge has force in direction of E. Negative charge has force in direction opposite to E.
    - Electric field strength (magnitude) doesn't depend on probe charges, only source charges. A charge doesn't feel its own field.
    - $E = kq/r^2$, away from q
    - Electric field of negative point charge points towards charge. For positive point charge, points away.
    - The force on a positive charge is in the direction of the field
    - The force on a negative charge is opposite the direction of the field
    - When we know the electric field, we can use it directly to find the force on a charge in the field using $F = qE$.

<u>CH. 23: THE ELECTRIC FIELD</u>

- Key electric field models
    - Electric field of a point charge (small charged objects)
        - Use superposition to find net electric field due to multiple point charges.
    - Electric field of an infinitely long line of charge (wires)
    - Electric field of a ring of charge
        - On-axis field only exists in the z-dimension
        - $(E_{ring})_z = kzQ/(z^2 + r^2)^{1.5}$

- Electric field of a disk of charge
    - Divide into concentric rings of charge
    - $(E_{disk})_z = \eta/2\epsilon_0[1 - 1/\sqrt{1 + R^2/z^2}]$
- Electric field of an infinitely wide plane of charge (capacitors)
    - Field strength directly proportional to eta
    - Field strength is the same at all points in space, independent of distance
        - Why? Distance from an infinite object means nothing; every point is “close to” infinite plane
- Electric field of a sphere of charge/spherical shell (electrodes)
    - Same as point charge Q at center of sphere
- Electric field of a dipole = formed by two equal but opposite charges separated by a small distance
    - Permanent = oppositely charged particles maintain small separation (like water molecule)
    - Induced = created by polarizing a neutral atom with an external electric field
    - Has zero net charge, but does have electric field.
    - Dipole moment *p* = vector pointing from the negative to the positive charge with magnitude qs, where s is distance between them
    - Electric field at a point on the axis of a dipole:
        - $E_{dipole} \approx 2kp/r^3$ where r is the distance from the center of the dipole
    - Not a point charge! Field of dipole decreases more rapidly than point charge (inverse-cube instead of inverse-square)
- Electric field lines
    - Continuous curves tangent to the electric field vectors
    - Closely spaced = greater strength
    - Widely spaced = smaller strength
    - Start on positive charges and end on negative charges

- Never cross

- Continuous charge distributions (vs. discrete point charges)
    - Linear charge density lambda = Q/L, Q = uniform charge on object, L = length
    - Surface charge density eta = Q/A, A = area
    - We can sum infinitely many tiny pieces of charge using integration
    - Problem solving strategy:
        - Divide total charge Q into many small point-like charges dQ
        - Use knowledge of point charge electric field to find field of each dQ
        - Find *E_net* by summing all dQ's
    - All of these electric field models above help us compute continuous charge distributions
- Parallel-plate capacitor

    - Net charge of capacitor is zero; plates are charged because of electron transfer
    - Inner surfaces of the plates can be modeled as two planes of charge with equal but opposite surface charge densities

    - Parallel-plate capacitor produces uniform electric field (same everywhere)

- Motion of charged particle in electric field
    - Source charges create fields, but other charges are affected by those fields. How so?
    - $F_{on\ q} = qE = ma$ where E is produced by some other source charges
    - q/m = charge to mass ratio; same ratio = same acceleration in E
    - Uniform electric field → particles will move with constant acceleration
    - Parabolic trajectories occur when there is constant acceleration. This requires a uniform electric force
    - Apply kinematics equations
- Motion of dipole in electric field
    - Field on axis: $E = 2kp/r^3$
    - Field in bisecting plane: $E = -kp/r^3$
    - No net force on a dipole in a uniform electric field
    - The sample becomes polarized by rotating with these torques
    - Torque = $pE\sin(\theta)$, where $p = qs$; $Torque = p \times E$

- Torque greatest with *p* is perpendicular to *E*, and zero when *p* is parallel to *E*
- Since angular acceleration = torque/moment of inertia, we can find acceleration
- Dipoles in a nonuniform field
    - Net force towards point charge/direction of the strongest field is exerted on dipole by field

CH. 24: GAUSS'S LAW

- A charge distribution is symmetric if you can translate/rotate/reflect it and it doesn't cause any physical change.
    - Symmetry of the electric field must match the symmetry of the charge distribution
    - Electric field of a cylindrically symmetric charge distribution cannot have a component parallel to the cylinder axis or a component tangent to the circular cross section
    - Planar symmetry = field is perpendicular to the plane
    - Cylindrical symmetry = field is radial toward or away from the axis
    - Spherical symmetry = field radial toward or away from center
- Gaussian surface = closed 3D surface through which an electric field passes
    - A Gaussian surface is most useful when it matches the shape and symmetry of the field
- Electric flux = similar to "flow"; amount of electric field passing through a surface; scalar-valued!
    - Of a uniform electric field
        - Angle theta = angle between velocity vector and normal vector to the plane
        - Flux phi = EAcos(theta) = dot_product(*E, A*), where Ecos(theta) is the component of the electric field that passes through the surface
            - Area vector *A* = A*n* is a vector perpendicular to the surface with magnitude equal to area of the surface
    - Of a nonuniform electric field
        - Compute by summing the fluxes through smaller pieces of the surface
        - Flux phi = integral over the surface of *EdA*
        - *dA* always points out of the surface

- Through a curved surface
    - If the electric field is tangent to the surface at all points, the flux = 0
    - If the electric field is perpendicular to the surface and has the same magnitude at every point, the flux = EA
- Through a closed surface
    - Include circle through surface integral, when over closed surface
    - Choose a Gaussian surface made up on pieces that are everywhere tangent to the electric field or everywhere perpendicular to the electric field

- Gauss's Law
    - Useful to finding electric fields in high-symmetry situations
    - Equivalent to Coulomb's law for static charges, but also valid for moving charges
    - Flux = Q_enclosed/eps_0 for a closed surface
    - Flux through any closed surface surrounding a point charge q is q/eps_0
    - Only applies to closed surfaces!
- Properties of conductors in electrostatic equilibrium
    - Any excess charge is on the surface
        - Interior electric field is zero since flux = 0
    - External field is perpendicular to surface
        - Flux = AE_{surface} = eta*A/eps_0
    - The electric field can be excluded from a region of space by surrounding it with a conducting box (called screening)
        - The Faraday cage is a wire mesh used for screening
    - A charge in the hole causes a net charge on the interior and exterior surfaces