



VR Fields

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October 25th, 2026

Why VR?

- E&M fields are usually taught with 2D diagrams
- But the fields themselves are 3D
- 2D drawings don't convey whole story
- So E&M feels counterintuitive and hard to picture
- VR lets students explore phenomena in 3D, leading to deeper understanding

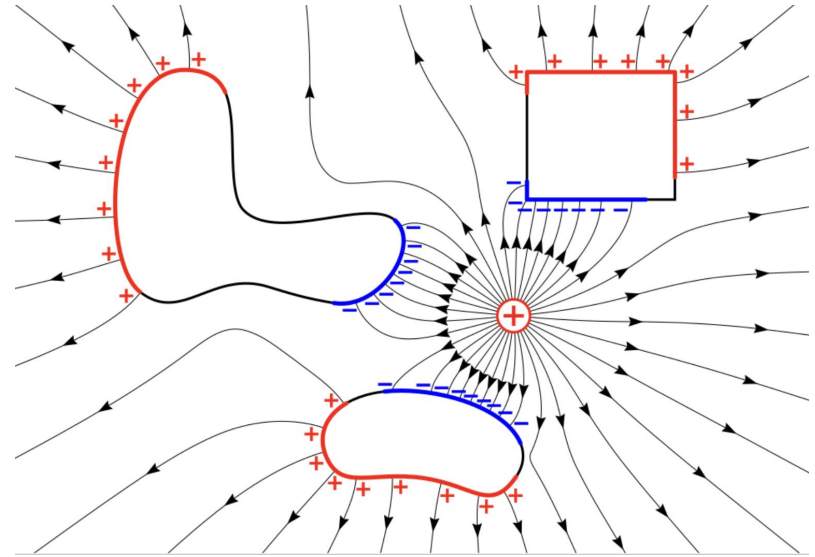
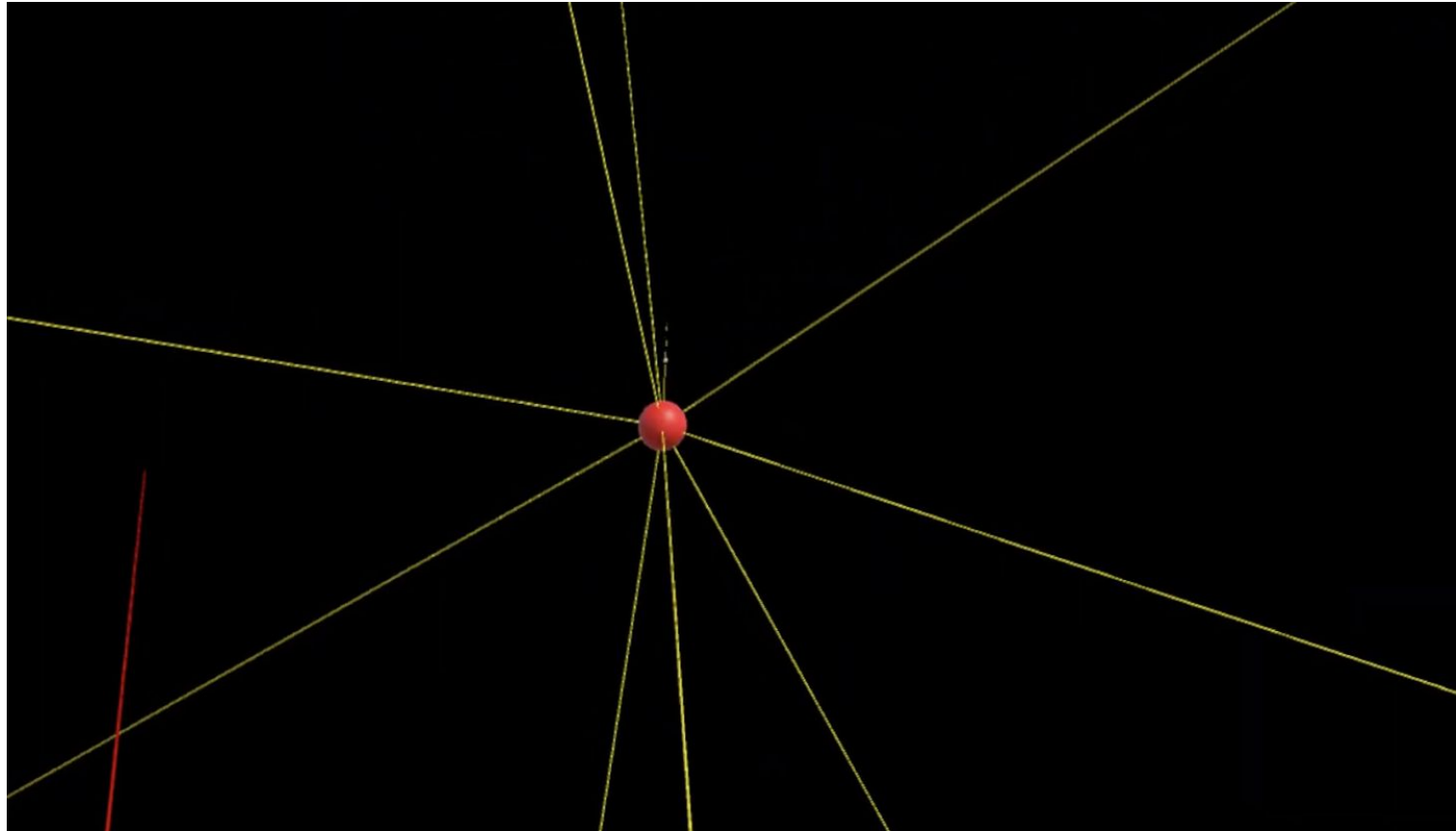
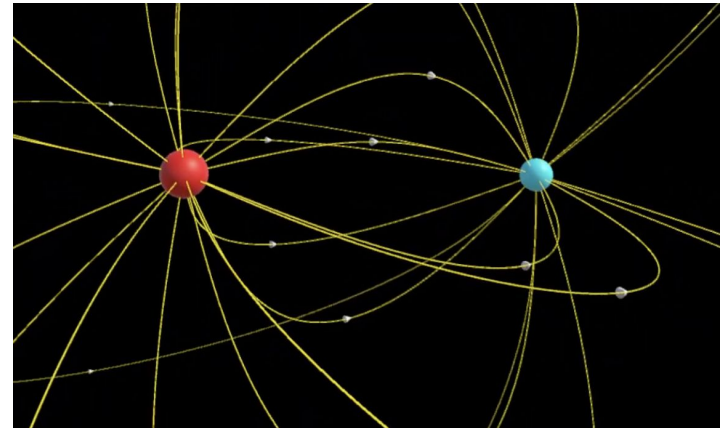
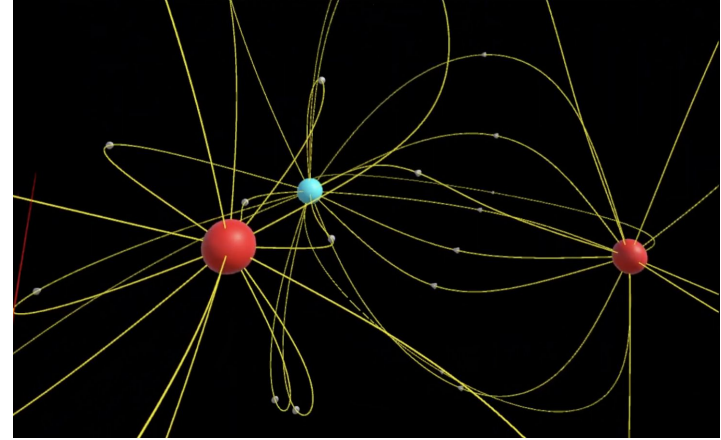
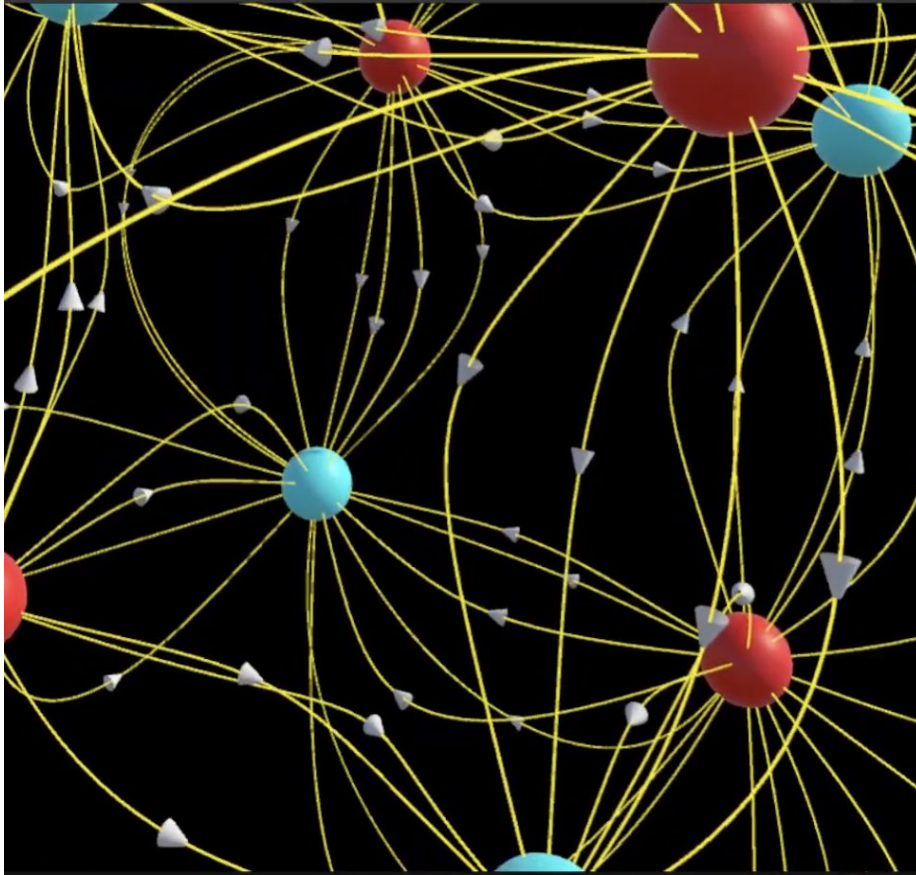


Image: "Electrostatic induction" by Chetvorno, Wikimedia Commons, CC0

Electric Fields: Point Charges

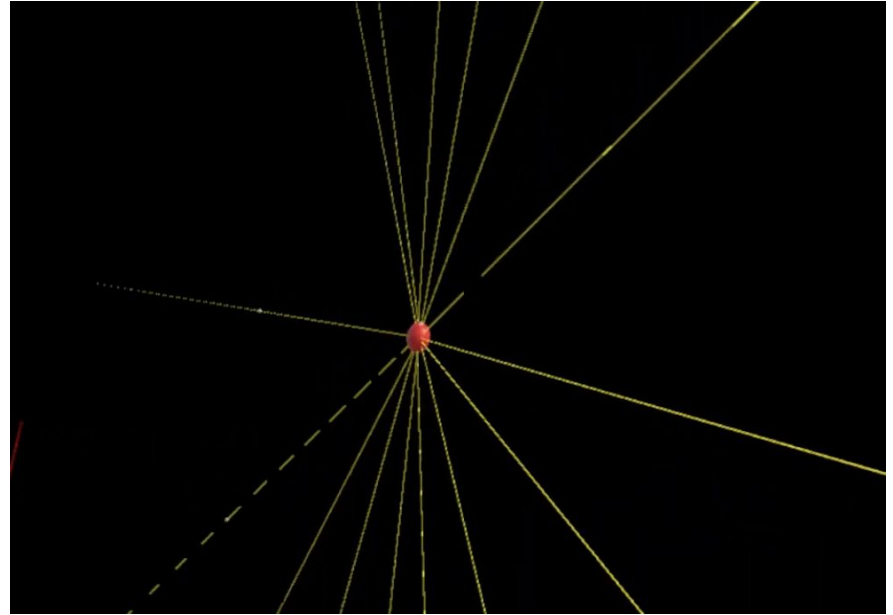
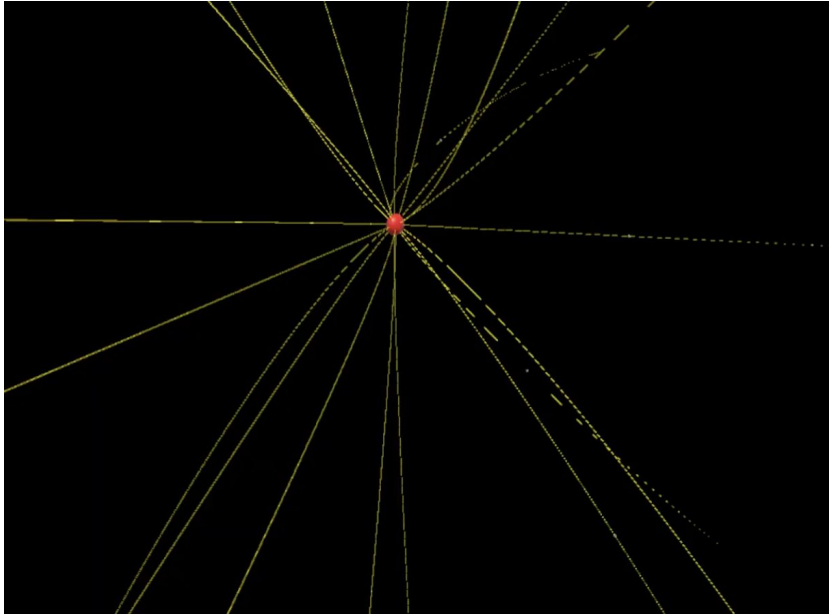


Electric Fields: Point Charges

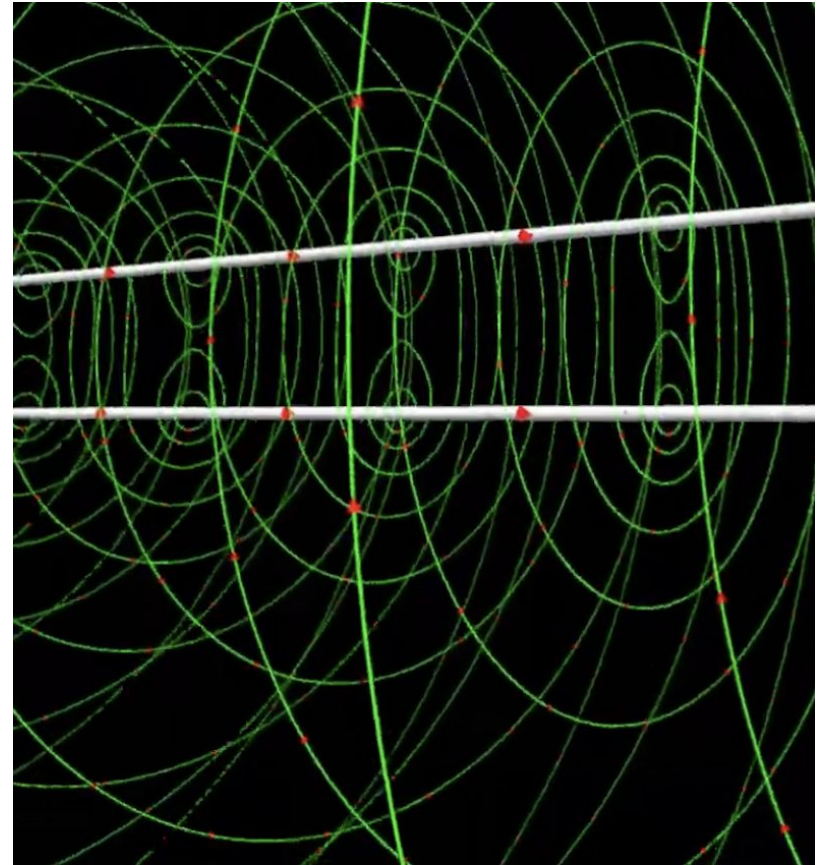
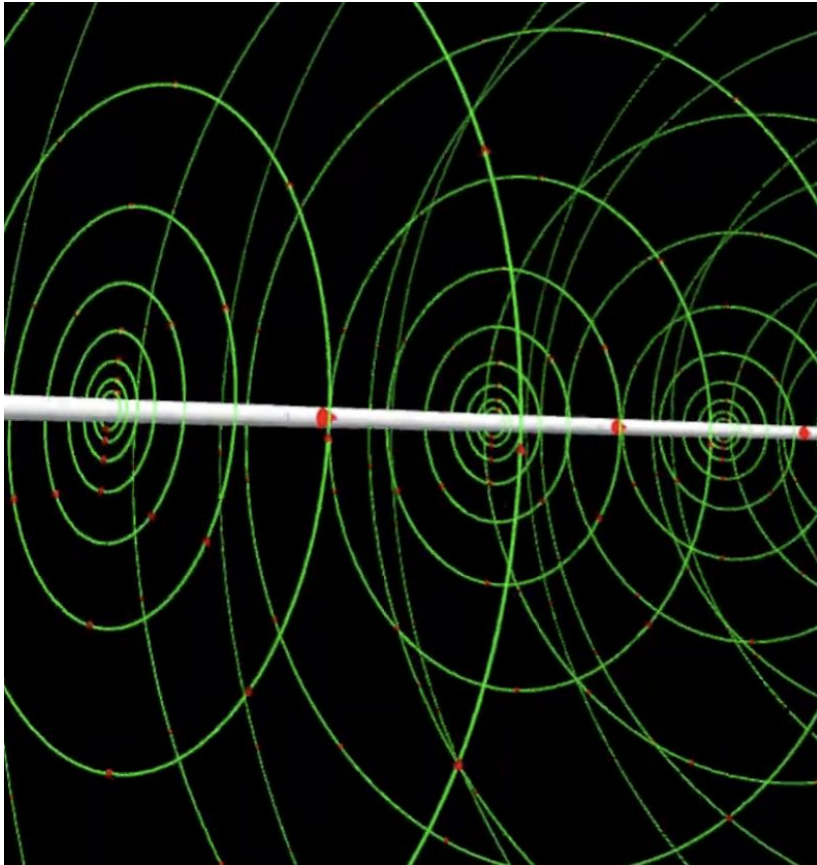


Electric Fields: Relativistic Particle

- User input: v/c ratio
- Displays: β , γ



Magnetic Fields: Straight Wires



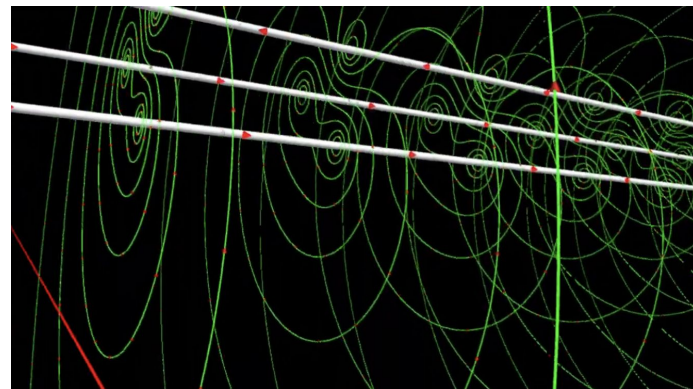
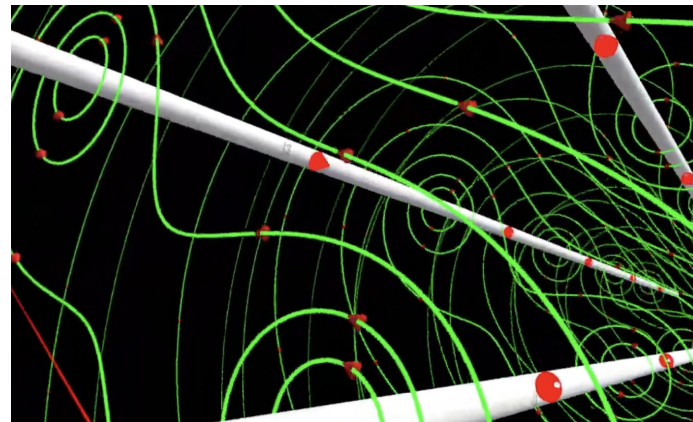
Magnetic Fields: Straight Wires

Controls:

- Separation between wires
- Strength of each current
- Toggle wires on/off

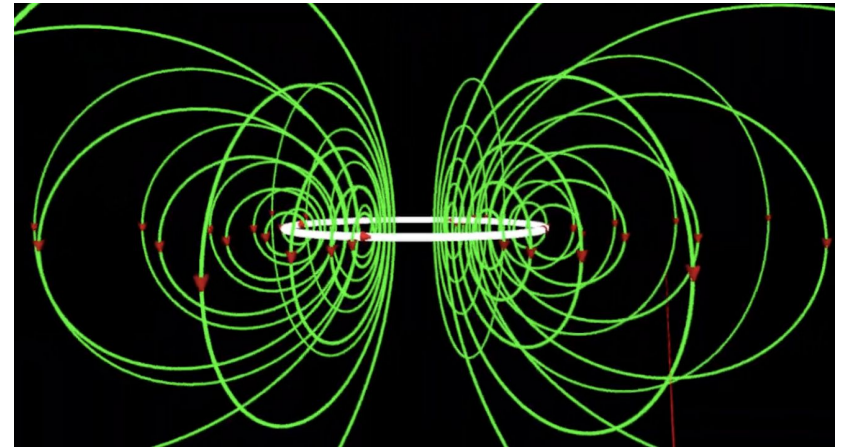
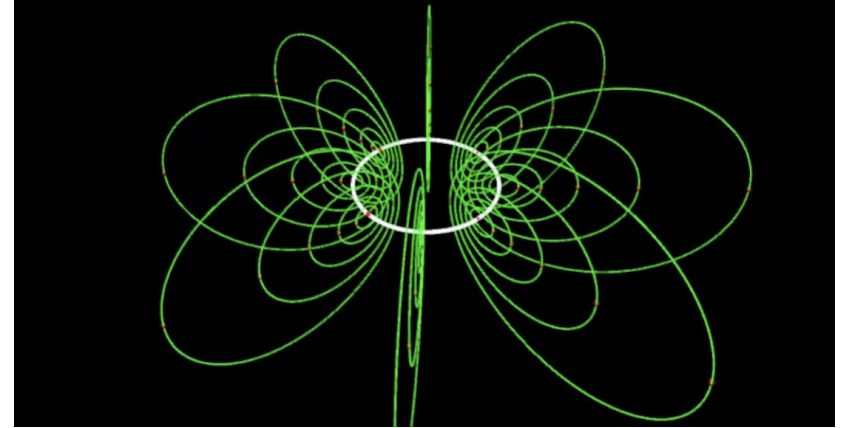
Varying Configurations:

- One wire:
 - circular field lines; their spacing grows with distance, because the field weakens as $1/r$
- Two wires, same direction
 - The fields cancel at a null point between the wires, nearer the weaker current.
- Two wires, opposite directions
 - The fields add between the wires, producing a strong field
- Three wires
 - Visualization of complex field, revealing non-intuitive patterns

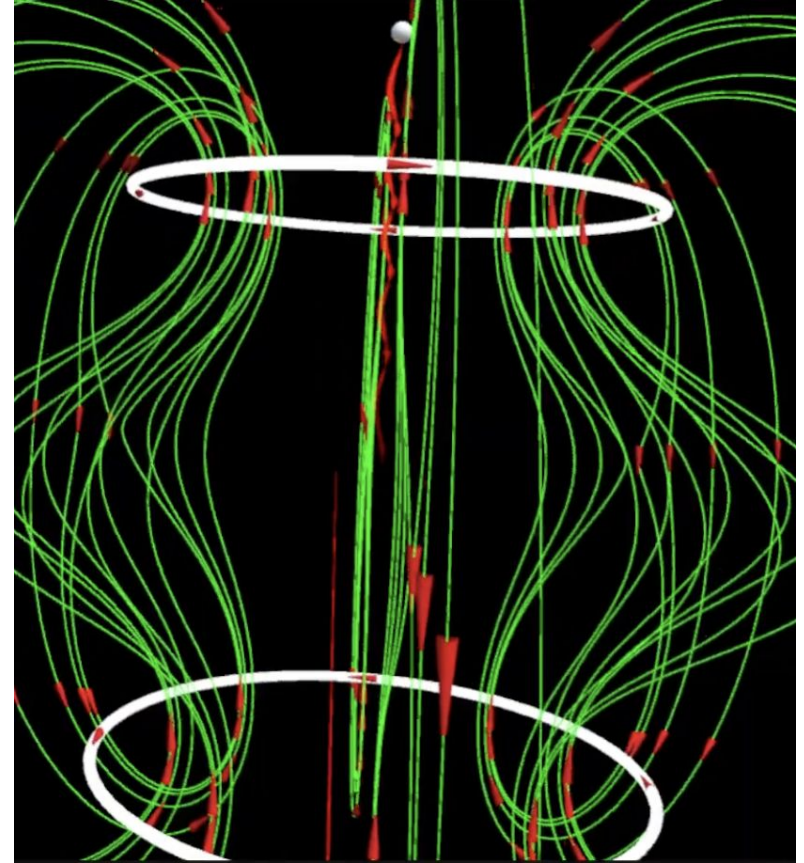
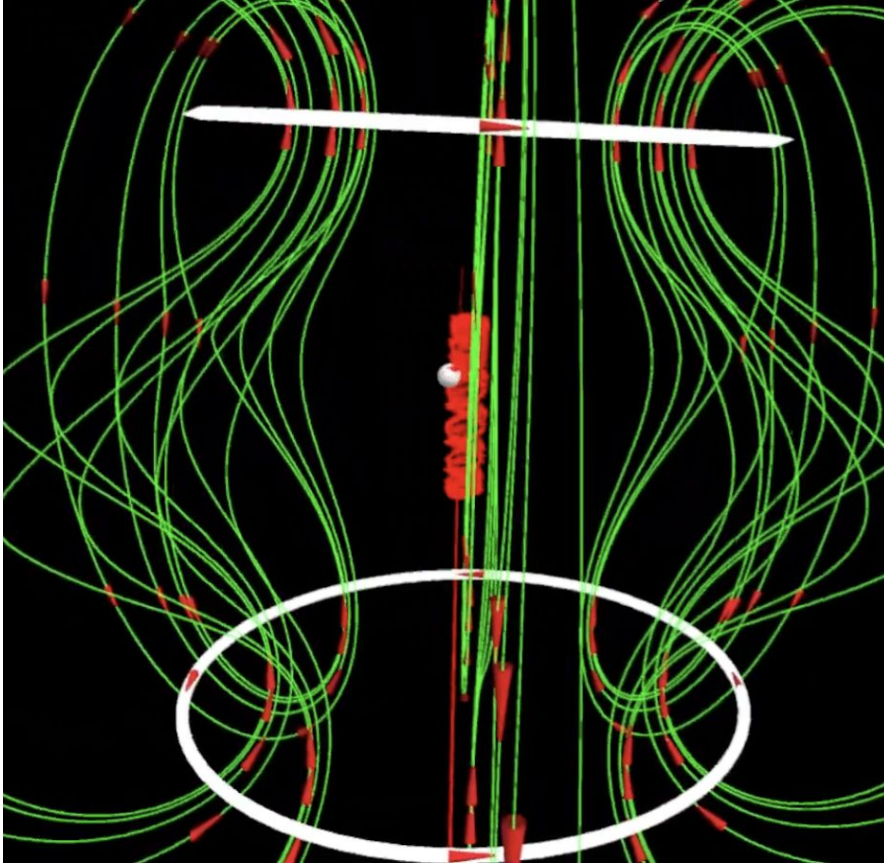


Magnetic Fields: Ring

- Near the wire
 - field lines circle the wire like a straight wire's
- Through the center
 - lines pass straight through the ring along its axis
- Outside ring
 - lines loop back around the outside of the ring, closing on themselves (magnetic field lines never start or end)
- At distance
 - the pattern becomes a magnetic dipole



Magnetic Fields: Bottle



Magnetic Fields: Bottle

- Pitch angle
 - The angle between the particle's velocity and the magnetic field at launch
 - Parallel to B: $v_{\parallel} = v \cos \alpha$ (no push from B)
 - Perpendicular to B: $v_{\perp} = v \sin \alpha$ (this makes the particle spiral)
- Ring separation & radius
 - Sets the bottle shape
 - Wider separation/smaller radius creates larger ratio between B at coils and B at center of bottle
 - A larger ratio converts more forward speed into circling speed on the way out, so more particles trapped
- Momentum
 - Sets the spiral size: $\text{radius} = p \cdot \sin \alpha / (qB)$
- Current
 - Sets the overall field strength: $B \propto I$ everywhere in the bottle
- Particle
 - Alpha (2 protons + 2 neutrons)
 - Proton
 - Electron

Integration Methods

- We need a way to trace the field lines or particle path
 - No analytical solution, must use numerical method
 - We can precisely determine the field at any given point in space
 - Based on the calculated direction vector, we take an informed 'step' to continue tracing (we can't calculate the field at infinitely many points along the line)
 - Taking a 'step' of any kind introduces some error
- Integration methods have different pros and cons
- RK4: for field lines
 - Weighted average of 4 points' directions to determine next step direction
 - Highly accurate—ensures field lines close properly/don't drift
- Boris: for particle motion
 - Rotates the velocity, so speed is conserved exactly and long runs don't distort the trapping
 - with RK4 sampling, no speed preservation (as magnetic field would ideally dictate)
 - Comes at cost of time
 - Angle of rotation is less, particle processes slightly more slowly

VR Fields: Summary

- Electric field lines with point charges
 - Prebuilt and custom configurations
- Relativistic electric field lines
 - Spans non-relativistic to very relativistic
- Magnetic field lines with straight wires
 - 1, 2, and 3 wires, varying current and distance
- Magnetic field lines with ring of wire
 - Dipole when far away
- Magnetic bottle for trapping particles
 - Varying bottle conditions, 3 particle options

