CHAPTER 22: ELECTROSTATICS 01/23/19

ELECTRICAL FORCE

- $\mathbf{F_E}$ vs $\mathbf{F_G}$: write down Law of Universal Gravitation and Coulomb's Law
    - $\mathbf{F_E = kq_1q_2/d^2}$ $\mathbf{F_G = Gm_1m_2/d^2}$
    - How is $\mathbf{F_E}$ like $\mathbf{F_G}$?
        - Varies inversely as the square of the distance
        - Can be attractive
    - How is $\mathbf{F_E}$ not like $\mathbf{F_G}$?
        - Can also be repulsive > positive and negative particles
        - Much stronger: $1\text{x}10^{23}$ times stronger than $\mathbf{F_G}$: almost one trillion trillion times stronger
    - Fundamental rule: likes repel, opposites attract
        - FIG. 22.1
        - ANIM: Repulsion & Attraction
- Why isn't all matter clumping up into a big ball or flying away if $\mathbf{F_E}$ is so strong?
    - Positive and negative particles combine together in "neutral" clumps: atoms, molecules, planets

ELECTRICAL CHARGES

- Positive and negative particles carry positive and negative charge, respectively
    - What is the most ordinary negative particle? Electron
    - What is the most ordinary positive particle? Proton
    - They combine (with neutrons) to form atoms.
        - Electrons are in shells or clouds about the nucleus, not orbits
        - FIG. 22.2
        - ANIM: Li atom
        - Why don't nuclei fly apart?

CHARGING

- Objects are generally electrically neutral
    - An object is charged when electrons are added or removed
    - Different materials hold on to electrons tighter than others – Chemistry!
    - Electrons move around in some materials better than others
        - Conductor: electrons in the outer shell aren't confined to a particular atom – they are free to move around in the material
        - Insulator: electrons are bound tightly to specific atoms
        - Metals conduct a million trillion times better than glass
- **DEMOS**: charging by friction
    - 2 plastic rods & fur: 2 people
        - before charging
        - after charging
        - plastic/fur & glass/silk: test for positive or negative
- During charging are electrons created or destroyed?
    - No, they are transferred – Conservation of Charge
- **DEMOS**: charging by friction

    - 2 plastic rods & fur: me
        - conservation of charge
- Quantized charge
    - No smaller charge exists on an independent particle than the charge of an electron
    - Every charge ever observed is some whole number multiple of the electron charge
    - When a quantity only comes in units of a particular size, we say that it is quantized – the smallest unit is called a quantum. In this case, electric charge is quantized and the charge of an electron is the quanta.
- **DEMOS**: charging by contact
    - Electroscope: plastic & fur: me
    - Tape: 2 people
        - Straight off the roll: positive or negative - rod
        - Discharge
        - Sticky-dry
        - Sticky-sticky
- Induction
    - Do you have to touch something to charge it?
        - You can redistribute the charges in an object by bringing a charged object near it.
    - Induction on a conductor
        - When a charged object is brought near, the electrons move around throughout the conductor
        - Two spheres example – charging
            - FIG. 22.7
            - ANIM: 2 sphere induction
        - One sphere example – grounding
            - FIG. 22.8
            - ANIM: 1 sphere induction
        - **DEMOS**: induction & grounding
            - Electroscope
                - Plastic & fur
                - Charge by induction
                - Ground (positively charged)
                - Bring plastic rod back
                - Bring glass rod back
                - Ground
    - Induction on an insulator
        - **DEMOS**
            - Wooden stick
            - Balloon on wall
        - When a charged object is brought near, the charges within atoms and molecules rearrange around their fixed positions - Polarization
            - FIG. 22.11, 22.12, 22.14

CHAPTER 22: ELECTROSTATICS 01/28/19

ELECTRIC FIELD

- How do forces act on things not in contact with one another?
  - They actually alter the property of space around them by creating a force field
    - Altered space around a massive object is its gravitational field
    - Altered space around an electrically charged object is its electric field
      - FIG. 22.16
  - You can think of other objects interacting with the fields and not directly with the objects producing the fields
    - Think of a rocket ship mission to the moon
- Electic fields have
  - Strength: E=F/q
  - Direction: the direction in which a small **positive** test charge would be pushed (direction of the force and the field are the same)
    - Vectors: arrows show magnitude and direction
    - Lines of Force: arrows show direction, strength is indicated by how close together the lines are
      - FIG. 22.17
    - FIG. 22.18: *Single charge, Two charges, Two plates*

ELECTRIC SHIELDING

- Review differences between electric and gravitational forces
  - Stronger, attract and repel
- Another difference, this time between the fields
  - Electric fields can be shielded. Why?
    - Because there are repulsive forces available to cancel out attractive ones
- Example: electrons on a spherical metal ball
  - Where do the electrons go?
    - FIG. 22.21 (sphere picture)
  - What force is on a test charge in the center of the ball?
  - What about a test charge 2/3 of the way across?
    - FIG. 22.20
- What about non-spherical conductors?
  - FIG. 22.21
  - Charge tends to gather at the regions of greatest curvature – to points
  - Think of charges added one at a time in a conducting cube. Forces push them as far away as possible until they start repelling each other more. Basically, they'll keep moving around until there are no net forces acting on them – the field in the conductor is zero. This tends to push charges out to corners or points – the areas of greatest curvature.
  - Lightning rods
    - FIG. 22.9

        - Charges tend to collect at the points of conductors
        - If electric field strength from a conductor gets large enough, it will ionize the air, i.e. strip electrons off of air molecules. Then the electrons (or positive ions) will leak onto the conductor, reducing the buildup of charge on the conductor.
            - How does the electric field get biggest where there is more charge when E=F/q?
        - So what is the primary purpose of a lightning rod?
        - What is the secondary purpose?

ELECTRIC POTENTIAL

- Electrical potential energy
    - Very similar to gravitational potential energy
        - FIG. 22.23: Massive object lifted vs opposite charges separated
        - FIG. 22.24: Spring vs like charges pushed together
    - A charge's potential energy depends on its location in an electric field (i.e. relative to other charges)
    - What if the charge in the example above is doubled? Tripled? Does the potential energy change?
- Electric potential
    - If we divide the potential energy by the amount of charge, then we have a quantity that is only dependent on the location in an electric field

      electric potential = electric potential energy/charge
      Voltage (Volts) = Potential Energy (Joules)/Charge (Coulombs)
    - What is an example of a thing for which it is convenient to know its potential even when there are no charges in its field? > A battery.
    - FIG. 22.25: Example charged dome and two different charges at the same position
    - Balloon rubbed on hair
        - Several thousand volts potential
        - How much energy? Very little because there is very little charge

VAN DE GRAAFF GENERATOR

- Device for building up large potentials (voltages)
- FIG. 22.30
- The static charge stays on the outside of the sphere
- If you increase the radius of the sphere, will you be able to build up more or less charge on the sphere?
- DEMO
    - Lightning: grounding wand
    - Pie plates; Styrofoam peanuts
    - Hair; fingers
    - Lightning rod
    - Ion propulsion

CHAPTER 23: ELECTRIC CURRENT 01/30/19

CHARGE FLOW & ELECTRIC CURRENT

- When does heat flow? > When there is a temperature difference.
- When does water flow? > When there is a water pressure (level) difference.
  - FIG. 23.1
- When does charge flow? > When there is a potential difference (voltage).
  - **DEMO:** Van de Graaff and fluorescent tube
- Voltage can be thought of as "electrical pressure" that produces a flow of charge.
- Electric current: the flow of charge
  - Generally, the flow of conduction electrons
  - Current is measured in amperes (amps), the rate of charge flow
    1 ampere = 1 coulomb/second
  - Current ~ Voltage
- Are current-carrying wires charged?
  - No. Current is generally not produced by adding extra electrons, but rather by moving the electrons that are already there.

VOLTAGE SOURCES

- Charge flow or current only continues as long as the potential difference exists.
  - Charged Van de Graaff generator = water tank with no pump
  - Battery or generator = water tank with pump
    - Batteries and generators work as electrical pumps, or voltage sources, by doing work to separate positive and negative charges so that the terminals are kept at different potentials
- Electric circuit: a closed system that can carry electric current
- The voltage gives energy to charges flowing in the circuit
  - Voltage (volts) = Potential energy (joules)/Charge (coulomb), e.g. a 12 volt battery gives 12 joules of energy to each coulomb of charge

ELECTRICAL RESISTANCE

- The amount of current in a circuit depends not only on how much voltage is supplied, but also on how much resistance the conductors have to the flow of charge
  - Water pipe analogy: a short, wide pipe has less resistance to water flow than a long, narrow pipe.
    - FIG. 23.4
  - Metal wire resistance
    - Short wires have less than long wires
    - Thick wires have less than thin wires
    - Higher temperature creates higher resistance
      - Superconductors: zero resistance at very low temperature
- Electrical resistance is measured in ohms
  - Lamp cord ~ 1 ohm
  - Light bulb ~ 200 ohms
  - Toaster ~ 20 ohms

OHM’S LAW

- The relationship between voltage, current, and resistance
  - Current (amperes) = Voltage (volts) /Resistance (ohms)
- **DEMO**: light bulbs
  - 1.5 V battery and 1.5 V/3 A lamps (0.5 ohms)

ELECTRIC SHOCK

- Damage from electric shock is the result of current – not voltage
  - Balloon had ~5000 volts, Van de Graaff had 100,000 volts but very little current, because there was very little charge flow
  - Current in a circuit depends on voltage and resistance
- Body’s resistance
  - ~500,000 ohms very dry, ~100 ohms soaked with salt water
- Touching a 9 volt battery
  - Dry (100,000 ohms): 0.00009 amps > can’t feel it
  - Wet (1000 ohms): 0.009 amps > stings
- Household outlets, 120 volts
  - Dry (100,000 ohms): 0.0012 amps > can feel it
  - Wet (1000 ohms): 0.12 amps > can be fatal, no hair dryers in the bathtub!
- Shock requires potential *difference*
  - Power lines
    - Hanging, birds
    - Third prong in power cords, FIG. 23.8

DIRECT CURRENT & ALTERNATING CURRENT

- Direct current: charge flowing in one direction
  - Batteries produce DC
    - Terminals always have the same sign and electrons are repelled from the negative terminal and attracted by the positive terminal.
  - Current can either be continuous or unsteady pulses
  - FIG. 23.9
- Alternating current: electrons flow in alternating directions, moving back and forth about relatively fixed positions.
  - Generators produce AC by alternating the polarity of the generated voltage
  - Almost all commercial AC in North America alternates at 60 cycles per second (60 hertz), and is normally provided at 120 volts.
  - FIG. 23.9

CHAPTER 23: ELECTRIC CURRENT 02/04/19

SPEED & SOURCE OF ELECTRONS IN CIRCUITS

- How fast do lights turn on or are land-based telephone calls transmitted?
    - Almost immediately at nearly the speed of light
    - Electrons do not move through a circuit that fast, the electric field does.
- In a DC circuit:
    - Electrons continue random motion plus a little extra nudge in the direction of the field within the conductor.
    - They collide with atoms in the conductor before they speed up very much.
    - The *drift velocity* is the speed at which electrons move along a wire. It is very low, only about 30 cm/hour in a DC car battery circuit!
- The electric field moves through the wire at nearly the speed of light
    - FIG. 23.13
    - Therefore, electrons throughout the entire circuit are nudged along almost simultaneously
    - A large current is possible not because electrons are moving so fast, but because billions of billions of electrons are moving all at once.
- In an AC circuit:
    - The electrons don't progress along the wire at all, they oscillate (move in rhythmic, alternating directions) about fixed points in response to an oscillating electric field.
    - For example, in a telephone conversation, it is the pattern of oscillations that is carried by the electric field at nearly the speed of light. Not the electrons, which vibrate where they are in response to the changing field.
- **DEMO:** dominoes
    - Sound or the mistaken view of electrons pushing each other along: a domino chain tipping over one by one.
    - Electrons responding to the electric field: a domino chain on a mat, with the mat pulled out from under them, moving them all at once.
- Source of electrons and energy
    - Water hose vs. wire: you can't buy an empty "electron pipe." The source of electrons is the conducting material, not the voltage source.
    - Electrons don't flow out of your home outlets, energy does. The energy is carried by the oscillating electric field. Power companies sell energy, not electrons.

ELECTRIC POWER

- Charges moving in a circuit expend energy by heating the conductors, turning motors, etc. The rate at which the electrical energy is converted into other forms of energy is called electric power.
    - Power = current × voltage ($P=IV$); in units, Watts = amperes × volts
    - 60 watt bulb in a 120 volt circuit draws ½ amp
    - $P = IV = I(IR) = I^2R$; $P = IV = (V/R)V = V^2/R$
    - Power = energy/time: electrical energy = electrical power × time; unit = kilowatt-hour

    - How much does it cost to run a 100 watt light bulb?
        - If your electricity (electrical energy) costs 10 cents/kWh,
          (0.1 kW) × (10 cents/kWh) = 1 cent/hour

ELECTRIC CIRCUITS

- A circuit is any path along which electrons can flow.
- A continuous flow requires a closed lop circuit with no gaps.
- Most circuits include a voltage source (battery or generator) and one or more devices that receive electrical energy.
    - Devices can be connected in series: a single pathway from the voltage source through all devices and back to the source.
    - Devices can be connected in parallel: each device is connected in a separate branch which forms a separate pathway for current.
- SERIES CIRCUITS
    - **DEMO:** lamps in series
    - There is one single pathway for electrons to travel, and they move in all parts of the circuit at once.
    - What happens if one device fails, i.e. burns out? The whole circuit is broken and all current stop s flowing.
    - Characteristics:
        - Since the current only has one pathway, it is the same everywhere through each device.
        - The whole current is resisted by the resistance of every part of the circuit: the total resistance is the sum of all of the individual resistances.
        - Current = Source Voltage/Total Resistance
        - Current = Device Voltage Drop/ Device Resistance
        - Total Source Voltage is the sum of voltage drops across all individual devices
    - ANIM: series circuit
    - What happens to the light intensity of lamps in a series circuit if additional lamps are added? The circuit resistance increases, which decreases the current in the circuit. Less current in each lamp means each lamp will be dimmer. The voltage drop across each lamp is less as well.
- PARALLEL CIRCUITS:
    - **DEMO:** lamps in parallel
    - Multiple devices connected to the same two points in a circuit
    - There is separate current pathway for each branch, i.e. through each device.
    - What happens if one lamp in a parallel circuit burns out? The current in the other branches is unchanged because their voltage and resistance hasn’t changed. However, the total current decreases by however much current the burned out lamp was drawing.
    - Characteristics:
        - The voltage across all devices connected to the same points is the same.

    - Branch current = Voltage/Branch Resistance, or
      Voltage = Branch Current × Branch Resistance
    - Total Circuit Current is the sum of the currents in all of the branches
    - The total resistance is less than the resistance of any individual branch. More branches means more pathways for charge to flow, thus less resistance.
  - ANIM: parallel circuit
  - What happens when more lamps are added? Nothing changes in the other branches, but the total current increases by the amount that the new lamps draw.

HOUSEHOLD CIRCUITS

- FIG. 23.19
- Wired in parallel for two reasons:
  - To keep the voltage, current and power for each device constant no matter how many other devices are added.
  - To prevent the failure of one device bringing down the power for the whole house.
  - OVERLOADING: in parallel circuits, when a device is added, its current is added to the total current for the whole circuit. If too many devices are turned on, the total current could get too large, overheat and start a fire.
  - FUSES: a fuse is connected in series on the main supply line so that the total current for the circuit passes through the fuse. The fuse has a wire that will heat up and melt if the current reaches a certain point. This breaks the circuit.
    - FIG. 23.20

CHAPTER 24: MAGNETISM ________ 02/06/19

MAGNETIC FORCES

- Force between charged particles depends on the magnitude of the charge and the distance between them: Coulomb's Law, electrical force
- But it *also* depends on the motion of the charged particles: magnetic force
- The source of magnetic force is the motion of charged particles
- Electric and magnetic forces are part of the same phenomenon: electromagnetism.
    - Since magnetism and electricity are part of the same thing, do you think magnetism is stronger or weaker than gravity?
    - DEMO: magnet and paper clips

MAGNETIC POLES

- Electric charges give rise to electric forces
    - Positive and negative
    - Opposites attract, like repel
    - Force depends on magnitude of charges and the distance between them
- Magnetic poles give rise to magnetic forces
    - North and south
    - Opposites attract, like repel
    - Force depends on magnitude of pole strengths and the distance between them
    - Single poles, or monopoles, do not exist, you can't have a north without a south
    - DEMO: compass and bar magnet

MAGNETIC FIELDS

- Electric charges produce electric fields, similarly magnets produce magnetic fields
    - DEMO: iron filings in liquid over a magnet
    - ANIM: field lines
    - Direction of field is from north to south
- Electric charges in motion have an electric and magnetic field around them.
    - The magnetic field is a relativistic byproduct of the electric field
    - Magnetic fields are produced by the motion of electric charge
        - What motion in a bar magnet?
            - Mainly electron spin (also electron revolution)
            - Most materials have equal numbers of electrons spinning in opposite directions within an atom, but some materials like iron have several unpaired electrons in each atom spinning in the same direction. In that case the magnetic fields of the electrons/atoms don't get canceled out.

MAGNETIC INDUCTION

- How do magnets pick up non-magnetic items, like paper clips?
- ANIM: magnetic domains

    - Many nearby atoms with a magnetic field due to unpaired electrons can get aligned with each other into “domains”. The domains generally are not aligned with each other.
    - When a magnet is brought nearby, it can induce the domains into alignment just like an electric field can induce polarization or charge in a material. Then the paper clip is attracted to the magnet.

ELECTRIC CURRENTS AND MAGNETIC FIELDS

- Moving charges produce magnetic fields, so electric currents produce magnetic fields.
    - The magnetic field about a current carrying wire has a pattern of circles around the wire
        - FIG. 24.8, 24.9, 24.10
    - DEMO: wire deflects magnet (battery, compass)
    - If the wire is bent into a loop, the field lines bunch up and get more intense, the more loops, the stronger the field.
        - FIG. 24.9, 24.10
- Electromagnets are current carrying coils of wire
    - Can get even stronger electromagnets by placing iron within the coil (domains in the iron are induced into alignment and add to the field)
    - DEMO: hex driver electromagnet

MAGNETIC FORCE ON MOVING CHARGES

- Gravitation, electric forces and magnetic forces between poles act along lines connecting the sources of interaction (masses, charges, magnet poles).
- Magnetic force on a moving charge deflects a moving charge perpendicular to both the magnetic field lines and the velocity of the charged particle.
    - FIG. 24.13

MAGNETIC FORCE ON CURRENT CARRYING WIRES

- Wire with current has moving charges on it, so if that wire is in a magnetic field, there is a force on the electrons within the wire, and thus on the wire itself.
    - DEMO: magnet deflects wire (battery, wire, horseshoe magnet)
- Electric motor: FIG. 24.19

EARTH’S MAGNETIC FIELD

- Why does a compass point northward? The earth is a magnet.
    - The configuration of the earth’s field is like a big bar magnet in the center of the earth tilted a bit from the geographic poles (~1800 km off), the discrepancy is called magnetic declination.
        - FIG. 24.20
    - Don’t fully understand why or how the earth’s magnetic field is generated
        - Can’t be a chunk of iron like a bar magnet – too hot inside for atoms to stay aligned

    - Most think it is charges moving around in the molten middle region of the earth, maybe from convection currents together with the earth's rotation
      - FIG. 24.21
- COSMIC RAYS
  - Protons and other particles shoot toward the earth from all over space. Solar activity can kick up the intensity.
  - Most are deflected by the earth's field, some are trapped in the Van Allen radiation belts
  - Cosmic rays can get through at the poles where the field lines are parallel to the incoming rays
    - These rays strike the atmosphere, making it glow like a fluorescent lamp – aurora borealis/australis

CHAPTER 25: ELECTROMAGNETIC INDUCTION 02/11/19

ELECTROMAGNETIC INDUCTION

- Current can be produced in a wire simply by moving a magnet in or out of a coiled part of the wire (or moving the coil in a magnetic field).
    - When this happens voltage is induced in the loop.
    - DEMO: horseshoe magnet through a loop connected to galvanometer
    - The more loops moving in the field, the more voltage is induced (twice as many loops leads to twice as much voltage, etc.)
    - The faster the magnetic field moves through the loops, the more voltage is induced.
    - Faraday’s Law: the induced voltage in a coil is proportional to the product of the number of loops and the rate at which the magnetic field changes within those loops.
    - Voltage is induced in a loop only when the magnetic field in the loop is *changing*.

GENERATORS

- If you move a magnet in and out of a coil repeatedly, the magnetic field in the loop changes alternately increases and decreases.
    - DEMO: horseshoe magnet through a loop connected to galvanometer
    - Therefore the direction of the induced voltage will alternate, which results in the production of alternating current
- It is more practical to induce voltage by moving a coil through a magnetic field, rather than moving a magnet through a stationary coil.
    - A coil rotating in a magnetic field is a generator
        - Identical to an electric motor except the motor has electric energy for the input and mechanical energy for the output. A generator has mechanical energy for the input and electrical energy for the output.
        - FIG. 25.7: motor and generator effects
        - ANIM: Motor, generator
        - FIG. 25.8: rotating loop in a field
        - FIG. 25.9: turbogenerator

TRANSFORMERS

- You don’t need wires to transfer electric energy from one place to another. You can induce voltage in a coil by moving a magnet in and out or by moving the coil through a magnetic field, but also by just changing the current in a nearby wire!
    - Remember that any current in a wire produces a magnetic field. For example the field generated by a coil of wire
        - FIG. 24.10: magnetic field lines
    - If you put a second coil nearby, the magnetic field lines from the first coil will extend into the second coil. If the current in the first coil is changing, the generated magnetic field extending into the second coil is changing, thereby inducing a voltage and current in the second coil.

        - The first coil connected to the power source is called the primary. The second coil that has voltage induced is called the secondary.
            - FIG. 25.11
        - If you put an iron core inside the two coils, it will guide and intensify the magnetic field leading to greater induced voltage.
        - If you power the primary with alternating current, then you have a transformer.
            - FIG. 25.12
    - DEMO: transformer, with power supply and light bulb.
    - What if the primary and secondary were farther away, much farther away? Radio transmission.
- Stepping up and stepping down the voltage in a transformer
    - If the primary and the secondary have equal numbers of loops, then the output voltage will equal the input voltage.
    - If the secondary has more loops than the primary, the output voltage will be greater (remember the more loops, the greater the induced voltage when a magnet (or magnetic field) moves through the coil). In this case the voltage is said to be stepped up.
    - If the secondary has fewer loops than the primary, the output voltage will be lower. In this case the voltage is said to be stepped down.
    - Primary Voltage/Number of Primary Turns =
      Secondary Voltage/Number of Secondary Turns
- Transformers cannot step up (or step down) energy or power. That would violate conservation of energy. The power used in the secondary is supplied by the primary. The primary gives no more power than the secondary uses. If small losses due to wire heating are neglected:
    - Power into primary = Power out of secondary
    - $(\text{Voltage} \times \text{Current})_{\text{Primary}} = (\text{Voltage} \times \text{Current})_{\text{Secondary}}$
    - If voltage is stepped up, current is stepped down and vice versa.

POWER TRANSMISSION

- How do we get electricity from the power station to your home?
    - First we have to produce the electricity: Generators
        - Need a power source to turn the turbines in a generator and produce a voltage.
            - Water falling – hydroelectric dams.
            - Steam – power plants using burning coal or nuclear energy as a source of heat.
        - Generated voltage is usually 25,000 V or less.
    - Next we have to transmit the electricity over large distances.
        - Nobody wants a generator in their backyard, so we need power lines to bring the electricity from the generator to the city.
        - It takes a lot of power to run a city, but sending large currents through wires will heat the wires and much of the energy will be lost.

- Power = Current × Voltage. Don’t have to send large currents if we can make the voltages very large.
  - Use a transformer to step up the voltage before it goes on the power line. Typically up to 750,000 V.
- Finally, we have to reduce the voltage for use in industry (440 V or more) or in homes (120 V)
  - Use another transformer to step down the voltage before it goes into homes.

FIELD INDUCTION

- What’s really going on fundamentally when we induce voltages and currents with magnetic fields, is that the changing magnetic field induces and electric field, which in turn produces voltages and currents
  - **Faraday’s Law**: An electric field is created in any region of space in which a magnetic field is changing with time. The magnitude of the induced electric field is proportional to the rate at which the magnetic field changes. The direction of the induced electric field is at right angles to the changing magnetic field.
  - **Maxwell’s extension of Ampere’s Law**: A magnetic field is created in any region of space in which an electric field is changing with time. The magnitude of the induced magnetic field is proportional to the rate at which the electric field changes. The direction of the induced magnetic field is at right angles to the changing electric field.
  - These two statements are two of the most important in all of physics. They are the basis for our understanding of light and electromagnetic waves.