a very good morning to all of you today we start with the first module of the course physics for class 12 and the first module is electrostatics electrostatics forms a part of a larger area of physics called electromagnetics so electromagnetics involves study of electric and magnetic fields ok we will start with some experiments in electrostatics some of you may have carried out similar experiments at home but those of you who have not i urge you to try out some of these experiments to see the excitement in physics

so i will start with a pair of straws here there is one straw here then another straw in my hand and what i am going to do is i have a wool woolen scarf which i will use to rub this straw i rub the straw a couple of times leave it i take another straw here and drop this a few times and then i want to see what effect it has you see its not even allowing it to touch its pushing the straw

so much repulsion is there you also notice that there is nothing connecting destroy and just draw there is no string there is no object there is nothing connecting these two straws but this draw seems to be pushing it what is happening why is this pushing that in fact this draw if i take to the other to i mean why is this straw pushing the straw without any apparent connection between these two let me similarly take a glass rod and rub with silk a few times and take it near the same surface you see it gets attracted this particular one repelled it is repelling it this one is attracting it

so it seems there are and this is this is getting attracted even if without my touching i could i put close to to the straw it gets attracted

so let me charge it again here it is getting attracted

so there seems to be two kinds of forces one which is repulsive between the straw and this draw is repulsive and another one which is attractive between this glass which is swiped by silk and this straw

so these experiments of attraction repulsion were carried out long long ago and this study of these effects is what electrostatics will consist of now you may have done this experiments at home for example if you rub this and take it near some pieces of paper here you see they are all getting attracted completely you may have seen this as effects on a comb if you comb your hair on a dry day it they attract paper they attract all other kinds of objects here in fact i can take this to a metal cylinder and it attracts a metal metal c i am not even touching the metal cylinder its attracting and moving the metal cylinder

so what is this force what is happening even if i do not have any contact between these two objects in fact these are called the electrical effects you may have noticed magnets at some stage of your life and here here are a pair of magnets as you can see here this magnet attracts another piece another magnet here very strongly in fact if you have a metal clip metal gets clip gets attracted metal slip gets attracted by the magnet

so there are two kinds of effects that you see here one is between ah metals which are which is a different kind of effect magnetic effect and one which is the charging effect which we have discussed here

so all these effects constitute the general field of electromagnetism and in the first module what we will discuss is electrostatics

so having seen some interesting demonstrations of electric and magnetic effects we will now start to study the subject in more detail look at ah forces between charges why ah what are the repulsive forces what are attractive forces and

so on as i mentioned before this forms a very important part of the subject of electromagnetics which ah has a which is one of the strongest forces in nature it is it dominates all atomic forces it it dominates forces which make atoms atoms making molecules molecules making solids all these forces which are responsible are all electromagnetic and character

so what we saw was if you rub wool with that plastic and if you take two such

rubbed plastic rods they seem to repel each other
so what we say is the plastic rods are getting charged similarly i showed that if i rub glass with silk then it seems to attract the plastic rod
so there seems to be two kind of forces one which is repulsive in character the other is in attractive in character
so the science of electricity and magnetism started way back in 600 bc when greeks observed that rubbing amber with wolf can attract objects in fact electron has come from a greek word which is electron which means amber in greek
so the science of electricity and magnetism since that time of observation of these forces developed for centuries until 1820 or
so when hans christian oyster showed that electric forces electric charge current can generate forces on magnetic needles and then beyond that point many scientists including michael faraday james clark maxwell integrated the fields of electricity and magnetism and we now have what the field is called electromagnetics electromagnetics
so to explain the presence of two kinds of forces electric repulsive and attractive forces it seems that there are two kinds of charges benjamin franklin call them by the name negative and positive in fact he could have given any pair of names to these charges but we call them negative and positive and you must remember in the negative charge there is nothing negative about it is just a nomenclature and what i showed in the experiment are the following effects that when the two objects repel each other that is because both of them have a similar charge
so what we observe is negative charges repel negative charges it
so happens that positive charges also repel other positive charges and we also saw an attractive force and that is because positive charges attract negative charges
so this charge is actually a fundamental attribute of the particle just like mass is a fundamental attribute now if you contrast this with gravitational attraction gravitational force gravitational force is always attractive because there is only one kind of mass and mass attracts another mass while in the attribute of charges there are two kinds of charges positive charges negative charges
so positive charges attract negative charges negative charges attract positive charges but if you have a positive charge and another positive charge they will repel each other if you have a negative charge and another negative charge they will repel each other now atoms consist of these positive and negative charges in fact atoms are made up of primary electrons protons and neutrons the protons and neutrons form the nucleus and occupy a distance of about 10 to the power minus 15 meters that is the nucleus
so all the protons and neutrons are sitting within this volume and then the electrons are actually surrounding this nucleus ah to a radius of about 10 to the minus 10 meters
so you have the nucleus consisting of electrons sorry protons and neutrons and you have the electrons surrounding this nucleus and the atoms the neutral atoms have exactly the same number of electrons and protons
so the net charge of a of a neutral atom is zero because the electrons and protons have exactly the same charge to experimental verification now both of them have exactly the same charge
so the number of electrons being equal to the number of protons in an atom the atom is usually neutral of course you can have situations where you can remove an electron from an atom and the atom can get positively charged because it will have an excess of positive charge compared to negative charge
so you can have you can ionize the atom you can have an atom which is not

neutral and you can you call this ions now charges have very important properties
so let us look at some of the properties of charge the first one is conservation of charge what this implies is total charge which is the sum of positive and negative charges in an isolated system is constant
so isolated means you do not allow any charge to enter from outside its completely isolated
so the total charge of this isolated system is a constant now it does not mean that you cannot generate charges inside but whenever you generate a negative charge inside the volume you will also generate corresponding positive charge
so there are effects taking place in nature in which ah gamma radiation can split into a pair of electron positron pairs one is a positively charged particle the other is negatively charged particle
so the total charge within that volume is remaining the same and this particular conservation law of charge is an experimentally valid fact the second one is quantization of charge now this is electric charge is always found in integral multiples of a basic unit of charge which which we will call e by the letter small e this is actually the charge on the electron e is the charge on the electron is the magnitude of the charge on the electron and it is also the charge on the proton and the value of e ah is known to be one point six zero two one seven double six two zero eight into ten to the minus nineteen coulomb this is a unit c represents a unit which we will again come across later called the coulomb and this is named after the scientist charles augustine the gloom and
so this is usually approximated as 1.
6 10 to the minus 19 coulomb now this is an experimentally verified fact that whatever charge you find anywhere is always an integral multiple of this number you cannot have a charge for example of 3.
01 10 to the minus 19 coulomb its not possible all charges will be integral multiple of this charge now this charge is a very very small number
so just to give you a feel for this number if you take the one centimeter cube of copper the metal copper the number of electrons and hence protons is about two point four into ten to the power twenty four
so ten raised to the power twenty four is one followed by twenty four zeros its a huge huge number and there are
so many electrons within the volume of a copper and for each electron you have a proton inside copper if you take a standard bulb for example in which you are passing current and you are getting light ah in one second about 10 to the power 19 electrons are crossing
so the electron charge is a very very small quantity of charge if you look at matter if there are
so many charges
so many numbers of charges that usually unless you are doing some very critical experiments at microscopic levels it will look as if the charge is continuous it look as if you can obtain any charge but we must remember that charge is a contest quantity and the total charge in any system has to be an integral multiple of the basic unit of charge which is approximately 1.
6 into 10 to the power minus 19 coulombs now charges also follow principle of additivity
so i will for example the charge on an electron will be minus 1.
6 10 to the minus 19 coulomb and the charge on a proton is plus one point six ten to the minus nineteen coulomb
so if you have a certain number of electrons and a certain number of protons you have few of n one electrons and n one n two protons total charge is n two minus n one into one point six into ten to the power minus nineteen square

so you algebraically add the charges
so if n one is equal n two like in a neutral atom the net charge on the atom is precisely zero now we will see as we progress that there are different kinds of materials called conductors and insulators broadly
so what are conductors conductors are those materials which allow free flow of electrical current in these materials there are electrons which are free and are able to move freely within the conductor
so examples are metals human body earth and
so on and because electrons are able to move freely in these materials if you put some charge into this into the metal an excess charge then the charge gets distributed over the entire surface y surface i will come to a little later
so the metals which we use in electrical circuits the metals all metals are actually good conductors and they have this electrons which can freely move within the material and hence they are able to conduct electricity very well insulators on the other hand do not have free electrons which can move around the material
so they offer a high resistance to electrical currents example glass plastic wood etcetera
so most materials that you see either fall into insulators or conductors and when you put a charge when a charge is put on an insulator it says it stays where it where you put it it stays at the same place because it has no freedom to move from one point to another point within the material there are another class of materials called semiconductors whose resistance to electrical conduction is between conductors and insulators examples are silicon germanium etcetera and these actually form the backbone of the electronics industry they are also extremely important because using these semiconductors one can build many electronic devices such as transistors diodes and
so on which form the basic component in most electronic circuits
so having seen some basic facts about positive negative charges and
so on we would now like to understand what are the forces between these charges how do they force how does the force depend on the distance between the charges how does the force depend on the magnitude of the charges etcetera
so we will start with coulomb's law there was a scientist french scientist called charles augustine the coulomb who did a number of experiments in seventeen eighty four to find out how the forces between charges vary as a function of separation how do the forces vary as a function of the magnitude of charges and
so on
so for example he took a pair of identical charges measured the force as a function of separation between the charges for various separations kept separation fixed varies the magnitude of charges and from all these experiments detailed experiments he found out a relationship between the force the magnitude of charges and the separation between the charges
so the law is called coulomb's law and this is a law which which tells the force between two point charges now i must point out that point charge here implies that the size of the charge distribution is very small compared to the distance separating the two charges
so that effectively the charge behaves like a point charge
so if you have a spherical ball which is charged if the size is say one millimeter and if you put two charges at a separation of say hundred centimeters this charge will almost behave like a point charge the law which we are i am going to write now is actually valid for point charges and it states that the force between two charge two point charges is proportional to the individual charges

so let me call charge one charge as q one another charges q two and the separation between them is r

so the charge the force is proportional to the product of the two charges it is also proportional to one by r square directly proportional to the product of the two charges and inversely proportional to the square of the distance between the two charges and it actually the force is along the line joining the two charges

so if i were to write the magnitude of the force it will look something like this some constant q one q two by r square now let me put a mod sign here because as we have seen the charges can be positive or negative

so i am just writing the magnitude of the force

so q one can be negative q two can be negative the force it could be attractive course force could be repulsive but all the forces are described by an equation like this and k is a proportionality constant proportionality constant and if you have done gravitational forces before this force is very similar to the relationship or gravitational force where instead of charges you had masses and ins

so instead of instead of distance instead of this the k has certain value

so instead of charges you had masses and the force of gravity is always attractive but the electrical forces can be repulsive or attractive now the proportionality constant k is written as one by four pi epsilon zero ah epsilon zero is a constant referred to as permittivity of free space now in one set of units which is the s i units which is what we will be using primarily through the course k is defined exactly as k is equal to 10 to the minus 7 newton second square by coulomb square into c square the c small c this is the velocity of light in free space and it has a definite value 2.
99792458 into ten to the power eight meters per second this is now fixed value of c this is the value of c defined and

so if you substitute the value of c into this equation please remember this is a unit is called coulomb square and this c is a velocity of line in free space

so this c is defined k is defined like this

so i can substitute this c into this equation and get an approximate expression value for k and that comes out to be eight point nine eight eight into ten to the power nine newton meter square by coulomb square

so if i substitute the value of c which i wrote here if i substitute the value of c here into this equation and i will get a defined value exact value of k and that happens to be approximately eight point nine nine eight and usually this is written as nine into ten power nine newton meter square by coulomb square

so this is the value which you will use and the definition of the it is in si units and the charges are defined in terms of coulomb the unit of charge is a coulomb which i had defined earlier and the electronic charge is 1.
6 10 to the minus 19 coulombs now that was a scalar relationship between the force of of attraction or repulsion between two charges now let me try to because force is a vector i need to define the actual force between two charges we would now like to calculate the force with direction and magnitude because earlier what i had said was only the magnitude of the force but i would like to also have a formula which tells me what is the direction of the force

so for this i will start by looking at two charges q one and q two ah i have a an origin here

so this vector joining origin to q one i will call r one vector the vector joining origin to q two i will call r two vector and this vector is r two one

so r two one vector is r two vector minus r one vector its a vector joining q one to q two

so q one and q two are two charges can be positive or negative

so i will define the force on the charge two q two because of the charge q one

as f two one is equal to one by four pi epsilon zero q one q two by r two one square into r two one unit vector
so here r two one unit vector is r two minus r one divided by magnitude of r two minus r one
so this is the force acting on charge q two because of charge q one the magnitude of the force is as we had written earlier one by four pi epsilon zero product of the two charges divided by the square of the distance between the two charges which is r two one
so r two one here is the magnitude of the r two one vector and the direction of the force onto on q two because of q one is along the unit vector direction r two one joining q one to q two now this formula is valid no matter what charges you take what the sign of the charges is
so for example if both charges were positive r one r two one unit vector is like this both charges are positive
so f two one is also like this that means the force is repulsive similarly if the first charge was negative the second charge was negative r two one unit vector is still like this and f two one also happens to be in the same direction because both are negative and the force becomes positive with respect to r two one vector
so again its a force of repulsion if you take one to be positive and q two to be negative r two one unit vector is still from one to two while f two one becomes oppositely directed because one of the charges is positive the other is negative
so the magnitude of the force is in the direction of the the force is in the opposite direction to r to one unit vector and that force becomes attractive
so these two forces are repulsive and this is an attractive force
so this formula is a formula which tells me the magnitude and direction of the electrostatic force between two charges q one and q two the force is proportional to the product of the two charges is mostly proportional to the square of the distance separating the two charges and is along a direction joining q one to q two where i am writing the force of force between force acted upon on q two by q one
so we will use this formula later to look at the total force on a charge in the presence of other charges ah we will introduce the principle of superposition later and calculate the net force acting on a charge when more than one charge is present surrounding the charge this force which i have written this equation is actually valid in vacuum or free space if you have a medium in between then the medium complicates the because the medium also consists of charges electrons and protons this force law has to be slightly modified and we will come to some discussion on electrostatics in the presence of media a little later in the course
so that is the force ah acting between two charges let me calculate just to give you an idea of the relative magnitude of the electrostatic forces and gravitational forces gravitation is always attractive electrostatic forces can be attractive or repulsive
so both are different kinds of forces
so let us compare and see what is a relative magnitude of these forces
so let me take
so let me com comparison of gravitational and electrostatic forces
so as an example we take two alpha particles
so this is an alpha particle there is another alpha particle now alpha particles are actually nuclei of helium atoms
so they have a charge of 2 e which is equal to 3.
2 10 to the minus 19 coulombs and the mass of this alpha particles is

approximately six point six four ten to the power minus twenty seven kilogram
so we take two alpha particles and they have the same charge
so they ripple each other they have masses
so they attract each other through gravitational force
so let us try to compare what is the force of attraction between these that will depend on the mass and what is the force of repulsion between these because of electrostatic forces that will give us an indication of the relative magnitudes of these two forces
so the electrostatic force f e is equal to one by four pi epsilon zero q square by r square where q is the charge on each alpha particle and r is the separation between the two alpha particles the gravitational force g m square by r square
so its q is the charge of the alpha particle m is the mass of the alpha particle g is the gravitational constant
so we can calculate ratio of electrostatic to gravitational force which will become one by four pi epsilon zero g into q square by m square the distance separating the two charges disappears from the equation
so this ratio is independent of the separation between the two charges whether they are close or far apart the ratio is independent of the separation
so now i can substitute the various values into this equation
so f e by f g is equal to ah one by four pi epsilon zero is approximately nine into ten to the power nine newton meter square by coulomb square divided by gravitational this is one by four pipe seven zero gravitational constant is six point six seven ten to the minus eleven newton meter square by kilogram square into q square
so 3.
2 10 to the power minus 19 coulomb square divided by the mass square which is six point six four ten to the power minus twenty seven kilogram square and
so if you simplify this this comes out to be approximately 3.
1 into 10 to the power 35 and astonishingly large number
so you can see that the electrostatic forces are much much higher than the gravitational forces with microscopic objects with macroscopic objects the charge cancellation between the positive and negative charges is
so perfect that if you have two objects like this although there are huge number of charges in the in both of these objects the electrostatic attraction is almost non-existent there is a gravitational attraction of course because the masses are very small the gravitational attraction you do not feel you need huge masses for gravitational attraction in fact the very fact that we are able to stand on the earth is because of gravitational attraction
so the charge cancellation between electrons and protons is
so perfect that in macroscopic objects unless you charge them like we did in the experiment the electrostatic forces are negligible remember that it is these electrostatic forces electromagnetic forces which are responsible for the atoms and molecules to join together to form solids liquids etcetera now as another very interesting example let me try to calculate what is the excess charge required to equal the gravitational attraction between two masses
so i am going to take as an example one kilogram mass another one kilogram mass and separated by distance of one meter
so i want to find out if these objects were neutral there is no electrostatic attraction or repulsion there is only a gravitational attraction how much excess charge between these two in these two masses assumed to be equal will create a force which equals this gravitational attraction
so now remember that the electrostatic attraction is one by four pi epsilon zero q square by r square the gravitational attraction is g times m square by r square these are magnitudes if i want these forces to be equal i must have one

by four pi epsilon zero q square by r square is equal to g times m square by r square and that gives me the following equation q is equal to square root of four pi epsilon zero g into mass
so because we have taken one kilogram mass this is six point six seven 10 to the minus 11 divided by 9 into 10 to the power 9 raised per half into 1 kilogram and that is about 8.
6 into ten to the power minus eleven coulomb the exchange excess charge required in each of these masses to counter balance the gravitational attraction i am assuming same charge
so there will be repulsion if i want to counter balance the gravitational attraction with charging put on the objects then even an excess charge of about eight point six to the minus eleven coulomb will result in a force which cancels of this attractive force now let me assume that these objects are made of copper its atomic number is 29 that means there are 29 electrons per atom 29 protons per atom now you can go go back and calculate that one kilogram of copper contains about 9.
4 into 10 to the power 24 electrons or atoms sorry atoms one car one kilogram of copper contains nine point four ten to the power four atoms each atom contains 29 electrons
so total number of electrons in one kilogram of copper comes out to be two point seven into ten to the power twenty six
so these are the number of electrons these are also the number of protons and
so the total electron charge if i multiply this by the charge per electron i will get about four point three into ten to the power seven coulomb
so please note that the there are
so many electrons in one kilogram of copper about 43 million coulomb charges and you need only an excess charge of about nine ten to the minus eleven
so the percentage of excess charge required is eight point six ten to the minus eleven divided by four point three ten to the power seven which is about two into ten to the power minus sixteen ah into hundred sorry percentage
so i have multiplied by hundred and that is 2 into 10 to minus 16.
the percentage of excess charge required is only 10 to the minus 16 to equate the gravitational force by the electrostatic force
so you can see the equality of charge between electrons and protons if one of them had slightly excess charge with equal number of protons and electrons in the material there would have been some excess charge and that excess charge would have resulted in such a strong attraction or repulsion that they would have completely counter balanced all gravitational forces
so nature has produced such an equality of the charges that matter normally is completely neutral because of the exact cancellation of the electron charge and the proton charges yeah i would like to leave a problem at the end of my talk for you to think about consider two point charges q one is equal to point five micro coulomb and q two is equal to one micro coulomb placed at a separation of ten centimeters if the charge q two is increase to 4 micro coulomb where should the charge q two be placed
so that the force on q one is the same as before one micro coulomb is equal to ten to the minus six you