

[Music] [Applause] welcome to this lecture module on optics in the last lecture we have we have seen a general introduction to the lecture module and optics in general and i have briefly touched upon three different approaches which are used in studying optics today we will try to start with the first topic and the first topic here is reflection of light and formation of images reflection of light and formation of images the approach that we are going to follow is one of ray optics as i mentioned in the first part we will start with the ray optics approach this will be followed by wave optics approach ray optics where light is discarded described the propagation of light is described in terms of propagation of rays and rays are straight line paths in a homogeneous medium in this course we will primarily discuss homogeneous media propagation in homogeneous media although one or two examples i may take up later of inhomogeneous media but primarily we are focusing on homogeneous media which means the ray paths are straight line paths therefore they also follow the rules and formulae which we encounter in geometry and therefore these also called geometrical optics this part of the discussion also forms what is known as geometrical optics geometrical optics approach

So first recall the law of reflection

So we know this is a plane mirror here a ray of incident light incident on a plane mirror or for that matter an interface between two media is reflected in such a way that the angle of reflection is equal to the angle of incidence the angle of incidence in the dotted line here represents the normal to the surface say this point is point p or point q the incident ray the angle between the incident ray and the normal is called the angle of incidence and the angle between the reflected ray and the normal is the angle of reflection which we have denoted as θ_i and θ_r

So the first point is that θ_i is equal to θ_r that is angle of incidence is equal to angle of reflection the second point is that now i have shown the same mirror in a little bit of 3d view here and the angle of incidence the point of incidence is p and r p is the incident ray and ps is the reflected ray the line here is a perpendicular line and a b c d what is shown here is a plane perpendicular to the surface of the mirror its a plane perpendicular to the surface of the mirror

So the second law or the second point about reflection is that the incident ray the reflected ray and the normal to the surface at the point p all lie in the same plane r p o p and p s lie in the plane a b c d this is the plane perpendicular to the surface of the mirror now an important point here is that if the ray was to reverse its path that is if the incident ray were to be like this then the reflected ray would have traveled along this because this would be θ_r and this will become θ_i and anyhow θ_i is equal to θ_r therefore a ray which is incident in the reverse direction will return in this way or this is called the reversibility of ray paths reversibility of rays the same thing is true here as well

So its the same thing i have shown it is in a plane a cross section plane and here a 3d view is provided

So this is about plane mirror now let us see reflection from spherical mirrors we are interested more on spherical mirrors because subsequently we will see that we will discuss some optical instruments and spherical mirrors and spherical optical components such as lenses are more widely used than the plane mirrors and therefore we are focusing more on spherical mirrors

So reflection from a spherical mirror in the last lecture we have discussed about some of the optical components

So what is shown here is a mirror this is the top view of the mirror

So the mirrors reflecting surface is here is the top view its a the spherical mirror is usually a circular section of a hollow glass sphere with a reflective coating on one surface

So let me show here that when we show a spherical mirror like this spherical mirror then note that this is part of a hollow sphere a hollow sphere its a circular section of the hollow sphere of certain radius of curvature

So if this is the center then this is the radius of curvature r

So the spherical mirror is a circular section this is of course a cross section in the plane is a circular section of a sphere of radius r and usually one surface is coated with a reflective coating such as silver coated surfaces

So that light incident on the light incident

So this is the coated surface and therefore this surface is opaque we already discussed this

So this is opaque and this is the reflecting surface the front surface is reflecting surface reflecting surface

So a ray of light which is incident here would get reflected there is no transmission on the other side later on when we will see about lenses we will see about refracting surfaces we will see that a part of the beam will also be transmitted but right now we are looking at mirrors where we assume that all the light is reflected back all right

So reflection from a spherical mirror

So this is the top view and this is the side view

So as i said it is a section of the sphere

So you can see it is a hollow sphere section of the hollow sphere

So this is the part where reflection takes place from this region

So this is the coated part the back side of that section and this is of course a cross section in the x y plane

So this is a concave mirror and a convex mirror concave mirror where the reflecting surface is on the front side and convex mirror is where this is coated from the inner side we have the reflective coating and the bulged side that is the convex side is the reflecting surface

So reflection from a spherical mirror we will see first this is the spherical mirror which is characterized by a radius of curvature and we will see reflection from a spherical plane

So here what i have shown is incident of a ray an arbitrary ray arbitrary ray means a ray which is incident and at any angle some arbitrary angle in other words if a ray is incident this point m could be here in which k if i start from some point then the point m could be here or anywhere

So that is why reflection of an arbitrary ray how do we determine the reflected ray first at the point of incidence m we draw a tangent we draw a tangent to the spherical surface and the normal to this here the normal will form normal to the surface and by law of reflection the reflected ray the angle of reflection θ_r must be equal to angle of incidence θ_i at that point

So every point every local point

So if i have this as the surface then every local point

So a ray could be incident like this or a ray could be incident like this array could be incident like this

So whatever way it is incident

So this point m is arbitrary whatever way it is incident then the rule is at this point you draw a tangent and then draw a normal at that point point of incident and then we know that if this is the angle of incident the reflected ray must go in a direction such that angle of reflection is equal to angle of incidence

So this is θ_i and this angle here

So let me mark it here is θ_r θ_r theta reflected

So if you have a ray which is incident like this again draw a tangent here to the surface draw a normal to this and then apply the law of reflection namely angle of incident is equal to angle of reflection

So this is for a concave mirror there the back side here is coated concave mirror

So if you have a convex mirror exactly like that

So if we have a convex mirror a ray of light is incident

So you draw the tangent and then draw the normal to the tangent and incidentally note that the normal to the tangent will pass through the centre of curvature because by definition any line joining the center to the circumference that is a point on the circumference of the radius of the circle will be normal to it at that point

So here it will be 90 degrees and therefore the normal for to locate the normal there is no need of drawing a tangent and locating the normal you simply link the center of curvature to the point of incident and you have the normal to the surface and then if the incident ray makes an angle θ_i the reflected ray will be in a direction where θ_r is equal to θ_i

So reflection from a concave mirror and reflection from a convex mirror reflection of any arbitrary ray c is the centre of curvature p that is the geometric center is called the pole

So we can have a look at this original diagram here

So this is the geometric center

So this is the pole which you can see that it is the at the bottom here p is in the same

line it is here p and its c r p all of them are shown in the same line

So p is called the pole we will see the importance of this pole in the next reflection of rays incident at the pole

So an incident ray at the pole as before this is the normal because the line joining the center of curvature to any point on the circumference will be normal at that point and therefore this is the normal angle of incidence is θ_i then the reflected ray will follow a path such that the angle of reflection is equal to θ_r note that whether it is a concave mirror or a convex mirror the ray of light incident at the pole will get reflected in this fashion θ_i is equal to θ_r a special case is if θ_i is equal to 0 which means if the incident ray is along the normal then obviously the law of reflection says that θ_r must also be equal to 0 in other words the reflected ray will be along the same path along the incident path that is because this is the normal So whenever area of light is incident on the normal then the reflected ray will also be along the normal this is true for concave mirror as well and therefore the normal ray in both the cases of convex mirror and concave mirror will be such that the reflected ray will be along the normal

So this the line joining the centre of curvature

So here is the center of curvature c and the pole p is called the principal axis

So this is called the principal axis principal axis principal axis

So a ray which is incident along the principal axis will be reflected back along the principal axis in the reverse direction next we consider reflection of a ray parallel to the principal axis

So here reflection of rays parallel to the principal axis

So what I have shown is consider any ray a ray which is incident here which passes through a point f here and another ray parallel ray also passes through the point f in other words what I have shown here is any ray which is incident parallel to the principal axis will pass through a point f or if I look at this plane the parallel ray the parallel rays or the beam will be focused to a point f

So this shows a converging beam please recall that a beam is a bunch of rays

So we represented in the last lecture that beam is a bunch of rays

So and a parallel beam a parallel beam or it is also called collimated beam parallel beam of light parallel beam just to distinguish between a diverging beam and a parallel beam

So in the last lecture we had seen that from the torch light you get a diverging beam

So here is our torch light then you have a diverging beam which is coming out and we said that a beam can be represented by a bunch of rays

So if parallel beam which is that is parallel rays incident on the mirror here we are talking of parallel rays parallel to the principal axis because I could as well have parallel rays incident like this

So this is parallel rays with oblique incidence to the principal axis

So I am not talking about this right now we will talk about this a bit later

So parallel rays parallel to the principal axis

So what I have shown in this diagram here is that rays incident parallel to the principal axis all focused to a point f called the principal focus how do we know this we will see just in a minute

So f is called the principal focus in the case of a convex mirror parallel rays the same parallel rays incident will diverge because every ray has to satisfy the law of reflection at the point of incidence then the net effect is that they will lead to a

diverging beam as you can see in this case a parallel incident beam was converging converging or focusing to a point here of course after the focus it is again diverging but we are looking at the focus focus is a point where an incident parallel beam

parallel to the principal axis will get focused that is called the principal focus in the case of a convex mirror the parallel beam results in a diverging beam after reflection however it can be seen that it appears that all the rays seem to start from

So this ray for example here this ray

So all reflected rays appear to come from a common point which is the principal focus of a convex mirror the principal focus of a concave mirror is in front of the mirror whereas the principal focus of a convex mirror is behind the reflecting surface and we will discuss the implications of this in front and behind and the sign convention and

So on

So parallel rays incident on a plane mirror now this principle focus the definition where I had said that rays parallel to the principal axis focus to a point f this is true under

what is called as a paraxial approximation paraxial approximation

So before proceeding further i would like to discuss about the paraxial approximation in this course we will consider all the geometrical formulations under the paraxial approximation this is a very good approximation in practice i will discuss in a minute but first what is paraxial approximation para axial

So this is actually the greek word para meaning close by nearby para axial

So close to the axis or near by the axis

So we are looking at paraxial rays paraxial rays which means rays which are close to the axis

So let me draw here separately

So here is the mirror and most of the times i am showing concave mirror but all discussions are equally valid for convex mirror

So this is the principal axis

So i have shown principal axis

So rays which are make which make let me use a different color

So rays which make a small angle with this

So this is the angle

So this is array incident ray

So this is the angle theta small angles for theta small small is a qualitative word small

So small means typically we are talking of anywhere from 0 to 5 degrees y 0 to 5 degrees

because the main point which we will use out of this paraxial approximation is whenever we have $\tan \theta$ or $\sin \theta$ this is nearly equal to θ we will use this

approximation $\sin \theta$ nearly equal to θ for small θ for small θ of course θ in radians here for small θ this is a very good approximation for small values of θ $\tan \theta$ is nearly equal to θ and $\sin \theta$ is nearly equal to θ this simplifies the mathematics and that is why we often ah often take course to paraxial approximation

So paraxial approximation

So paraxial approximation in which we deal with the rays which are either it could be parallel rays when θ is zero it is parallelized

So rays which are close to the principal axis they could be parallel rays or rays which are making small angle with the axis rays which make very small angle with the axis

So then we say that we deal with paraxial approximation this is also sometimes called small aperture approximation small aperture approximation let me explain what this means small aperture approximation approximation if we consider an optical system

So an optical system optical system means means a device which or a system or an arrangement an arrangement an arrangement with several optical components of course to form some device like for example you we will discuss later we will discuss optical microscope where we will see that there will be one lens here and another lens here and they will be i am not discussing any detail here and they will have a certain separation between them

So this is the axis of the optical system

So there is one lens l one and one lens l two i just want to explain what is meant by this small aperture approximation

So if you have an input aperture there is a block here aperture

So if i have an aperture which restricts the which restricts the extent over which light can enter the system for example light enters in this system

So if i make a small aperture and light enters and then maybe i do not know it may be travelling whatever way i do i do not i am just showing some rays but if you see if the aperture is very small then only rays which are close to the principal axis can enter and can propagate further ray like this can also enter but then it may go out of the system a ray which enters at a deeper angle will go out of the system only rays which are close to the axis which makes small angles or very close to the axis will pass to the next component and finally give whatever result at the output here

So an optical system which has a small aperture primarily deals with paraxial rays an optical system with small aperture primarily deals with paraxial rays and under paraxial approximation we will discuss the rest of the geometrical optics in this course

So let me keep the diagram which i have drawn here and just paraxial approximation

So i have shown some rays here

So array which is making a small angle θ a parallel ray but very close to the axis

So all of them as you can see the extent over which it is incident on the mirror is very

close to the axis

So a small aperture which means if I put an aperture here if I put a block here let's say I put a block here block means an aperture and which blocks rays which are coming from other side then it will not affect these rays because they are going back and forth or I do not know whatever it depends on the optical system that we are discussing for example if I take I showed the microscope in the earlier case for example there are optical resonators in the last lecture I showed a laser a laser has an optical resonator with two mirrors like this and the rays go back and forth the rays travel back and forth inside and resonate

So they travel like this note that typically this length could be few of the order of 10 centimeters let us say 10 cm if I take a helium neon laser this could be of the order of 10 centimeters and the mirror here could be of the order of 1 to 2 centimeters 1 to 2 centimeters and this distance could be 10 20 centimeters then we can see that any ray which makes a deeper angle an angle which is larger with the optic axis of the system will simply go off the system it will not hit the mirror and come back therefore only rays which are close to the axis which makes small angles will go back and forth in this resonator this called an optical resonator an optical resonator and just giving another example of an optical system an optical resonator is a device comprising of two mirrors it could be spherical mirror or plane mirror and

So on with a certain separation and usually the separation and the dimensions are such that only rays which are close to the axis resonate inside this device other rays simply go off and therefore we are automatically dealing with paraxial rays and this paraxial approximation is very widely applicable in many components and devices in optics

So it is as in the first course it is good enough for us to discuss paraxial approximation

So small aperture approximation or paraxial approximation the small aperture will lead to paraxial rays

So paraxial rays close to the axis and oblique rays which subtend small angles this is no hard boundary again this is just I am saying say a range of zero to five degrees may be six degree five point five degree does not matter now let me come back to the problem where I said that all parallel rays which are incident on this get focused to a point f So we said how do we know this let's discuss this

So here I am discussing this topic focal length of a spherical mirror

So we have consider incidence of a parallel ray of light a paraxial ray a parallel ray at the point of incidence m

So the reflected ray will follow a direction such that the angle of incidence this is the center of curvature joined to the point m gives us the normal this is the angle of incidence θ_i and angle of reflection θ_r is equal to θ_i and in this geometry we can clearly see that if this is θ_i which is equal to θ_r then this angle is also θ_i because this is parallel to this this is the principal axis

So incident ray is parallel to the principal axis

So this is θ_i this is θ_i therefore this angle is two θ_i

So immediately if I drop a perpendicular from m to the point d here then $\tan \theta_i$ $\tan \theta_i$ is equal to $m d$ by $c d$ $m d$ by $c d$ and $\tan 2\theta_i$ is equal to $m d$ by $q d$ for paraxial rays the point m is close to p we can see that we are discussing about paraxial rays which means small aperture approximation this point d is very close to this because we can see this clearly that if I have the principal axis here when the ray is very close to this and perpendicular dropped from here that is this is point d and this is of course point p the pole and this is the incident ray and this is the principal axis is the mirror then then any distance if I consider this as the center of curvature c $c d$ or $c p$ is nearly equal that is $c d$ is nearly equal to $c p$ and similarly if I had a point as in the diagram $q d$ here there was a point q then $q d$ is nearly equal to $q p$ this is true if the point m is close to the axis or we are dealing with paraxial rays suppose I was to deal with a ray which is incident here even a parallel ray which is incident far away then if I drop a perpendicular here d then $c d$ would not be nearly equal to $c p$ and therefore whenever we have a small aperture approximation a small aperture approximation then the point m is close to the point p this is close to the pole and therefore $m d$ the part the perpendicular which is dropped here is such that $c d$ is nearly equal to $c p$ So for paraxial rays point m is close to p $c d$ nearly equal to $c p$ is equal to r r is the radius of curvature because as I have already said this is the center of curvature the spherical mirror is part of a sphere and $c p$ is that the distance is called the radius of

curvature similarly $q d q d$ is nearly equal to $q p$ further we are dealing with paraxial rays and therefore $\tan \theta_i$ is equal to θ_i and $\tan 2\theta_i$ is equal to $2\theta_i$ this gives us $\theta_i \theta_i$ is equal to $m d$ by $c d$ which is $c p$ which is equal to r

So θ_i is equal to $m d$ by r and $2\theta_i$ is equal to $m d$ by $q p$ this implies that $q p$ is equal

So if you divide one by the other you can see $q p$ is equal to r by 2 $q p$ is equal to r by 2 r is the distance $c p$ radius of curvature $q p$ is equal to r by 2 for a parallel incident ray now this $q p$

So what we have got is $q p$ is equal to r by 2 radius of curvature is constant for a given mirror and therefore this is a constant what does this mean we have taken a parallel ray where incident at a point m the parallel ray could be here the parallel ray could be incident here the parallel ray could be incident here which means the point m is arbitrary and the point m or $m q$ or $m d$ none of them appear in the expression

So what it says is any parallel ray will pass through q because the distance $q p$ is fixed for a parallel incident ray whether the parallel incident ray is here or whether the parallel incident ray is here that is whether this is m it does not matter it simply says it will pass through a point such that $q p$ is equal to r by 2 it means any parallel ray will pass through q the point q is called the principal focus and designated as f

therefore this point q initially I had taken a general point q but now we have showed that all parallel rays pass through the point q and therefore now I am calling it as f which is the principal focus and we can see here in the next diagram I have shown that all parallel rays pass through this point q the distance $f p$ is called the focal length the distance from the point f this q is the same as f

So we have designated this point q now as f after showing that all parallel rays pass through it which means a beam comprising of parallel rays will get focused to the point f because it is a converging beam

So it will get focused at the point f and that is why it is called principal focus and designated by f the distance $f p$ is called the focal length f and therefore what we have shown is we have shown $q p$ as r by 2

So $q p$ is equal to $f p$ is equal to f or what we have shown is f is equal to r by 2 .

So in this small derivation what we have shown there are two points which we have shown that all parallel rays converge to a point which we call as f which is called as f the principal focus and the focal length $f p$ is shown to be equal to r by 2 where r is the radius of curvature of the spherical mirror all under the paraxial approximation or when we consider small aperture this relation holds good what about parallel rays incident inclined what about parallel rays inclined to the principal axis parallel rays but now they are not parallel to the principal axis they are inclined at an angle how would they look like

So please see this

So when parallel rays are incident on a plane mirror they reflect and they are parallel the ray the beam remains parallel because all the rays remain parallel to each other every ray satisfies the angle of incidence is equal to angle of reflection but the beam remains parallel whereas if there is a inclined ray inclined parallel beam which is inclined to the principal axis then they will get focused to a point but that point q lies on a plane containing the focus if we had parallel rays incident which are parallel to the principal axis they would have focused to the point f but if the parallel rays are inclined at an angle then they will focus to a point q this can be shown they will focus to a point q but it lies on a plane containing f and that is called the focal plane the focal plane I have also shown the corresponding diagram for a convex mirror here we are not going to the proof of this but we see that when the parallel rays are inclined at an angle then the focused point the point where it is focused or the point from where it appears to come after reflection is shifted from the point f but remains on a plane called the focal plane with this background we will now proceed to formation of image formation of images first we consider image of a point object if there is a point object where will be its image what is this point object it could be a point source it could be anything we see for example we see objects because objects reflect or scatter light which is incident on them

So in darkness for example we cannot see any objects in perfect darkness

So when we see object it means object is scattering or reflecting rays which are incident on them and they will form an image

So where will the image of an object be this is what we want to see because as we know the common application of all the mirrors is to see images including the plane mirror which we use for look at the looking mirror where we see our face or when we use for dressing or a concave mirror or a convex mirror which are used in various applications is to see the image of an object therefore it is very important to know how the images are formed in a mirror and what is the location of the image and what type of image is formed So that will be the next part of the discussion and there we are

So to begin with we start with the plane mirror and a point object

So here o is a point object

So there is o point object

So if we want to ah discuss about image formation lets say there is a mirror here

So let me draw this here and then i will put the figure which i have a pre drawn figure

So if this is a point object then this will give out rays in order if it is a point source it will give its own rays but otherwise if it is just an object then it even it is illuminated by light say the room light or any other light then it will reflect or it will scatter light in all directions

So this object may give out light in all directions what we want to see is these rays which are incident on a mirror where will they go after reflection and what kind of image because this is coming from a point and therefore if the rays again converge to a point that point will be called as the image point

So this is what we want to discuss first we take a plane mirror and then we will go over to spherical mirrors and we look at a point which is sitting here and c consider just one ray which is coming at an angle and a ray which is incident normally and then we use the basic rules which we are aware of that is if this is a plane mirror then the ray which is incident normally on the mirror will be reflected back and the ray which is incident at an angle

So this is the normal to the mirror

So this is the angle of incidence theta i then this will be reflected at an angle such that theta i is equal to theta r

So this ray is travelling in the reverse direction this tray is travelling in this direction we they do not seem to meet anywhere however if we take this ray backwards then we will see that from this point

So this is our object point this is the image point or from this point these two rays appear to come from this point i and such point is called the image point it appears to come its not the rays are not coming from there because there is no ray on the other side here there is no ray here rays are only in the front side but they appear to come from if we project them backwards then they appear to come from a point i and that is the image point and that is what is shown in this diagram which i have drawn already a pre drawn diagram

So we see the object o here the incident ray normally will be reflected back the ray which is incident at an angle will be reflected here

So if we take this back then it intersects at a point i from the geometry here we can clearly see that this angle if this angle is theta i that is incident angle is theta i then this is theta i and this is theta i and this is 90 degree and therefore all angles are the same and they have one common side here and therefore triangle o a b this triangle and this triangle are congruent triangles which means ob is equal to i b this distance i b is equal to ob what it means is the virtual image is a virtual image a virtual image is a image point

So this is a virtual image because the rays are not physically travelling there there are no rays existing in this direction it only appears as if this ray and the ray which is returning back come from this point i therefore this point i is called a virtual image point

So i is the image point it is a virtual image point it is a virtual image point without loss of generality we could have taken any ray at any angle we have taken a point a here but the point a could as well be here this could have been a this could have been a any of these could have been a and every time we will see that if this were a we see that this triangle will become these two triangles will be congruent it tells ob is equal to this if this were the ray then these two triangles will be congruent and again it gives ob is equal to ib in other words every ray which is coming out of the object is such that all the rays all the reflected rays appear to come from this point i which is the image point the point a is arbitrary which means it could have been any of the point it could

have been anywhere here and therefore i is a virtual image point this is how we can locate the image of a point object in front of a plane mirror why are we first interested in a point object because any extended object can be represented as number of point objects that is points on the object on the extended objects each point on the extended object can be treated as an independent object and its location can be found out by applying the laws of geometrical loss of reflection and subsequently of course refraction and we can locate the image corresponding to that point and when all the points all the image points when we get all the image points we get the total image of the extended object that is why we start with a point object now if i see the point object of a spherical mirror due to the point object in front of a spherical mirror and try to locate its image point then lets see the image of a point object in the case of a spherical mirror

So here is the spherical mirror here is the point object o and we consider two rays one ray which is travelling along the principal axis and we have already seen that it will be reflected back along the same direction a ray which is propagating in this direction an arbitrary direction it is that is this point q could have been here as well in which case i have to join o to q

So that will be the ray path oq

So oq is the ray path incident ray path on the mirror it will follow the law of reflection and get reflected because c is the centre of curvature the line joining c and q is the normal to the surface and the angle of incidence the small angle here and the angle of reflection must be equal

So that leads to the reflected ray which is propagating along this line it intersects the second reflected ray at the point i

So the point of intersection must be the image point

So by taking the earlier example here what we have shown is we considered two rays and the point of intersection in this case it is a virtual image point that is they appear to come from this point the point of intersection is the image point

So in this case the image point is the point of intersection of two real rays that is the ray actually travels here and gets reflected this ray the ray along the principal axis propagates here and gets reflected and comes back along this line and at the point i this ray would go further at the point i the two reflected rays would intersect which is the image point this is a real image because real image is the intersection of real rays whereas in the earlier case it was an intersection of two virtual rays that is there are no rays on the other side of the mirror but they appear to come from that point which was the image point

So the point q is arbitrary and therefore the object distance and image distance image distance will satisfy a relation independent of q we will show this that the object distance o to p this point is p pole op is called the object distance ip is called the image distance we will discuss this in detail we will show shortly that the object distance and image distance has a certain relation which is independent of the point q

So the point q is arbitrary the object distance and image distance will satisfy a relation which is independent of q and therefore the image point will be this these considering any two ray will be sufficient all other rays will come to the same point i because this object this point that we have chosen is arbitrary all other ray means what a ray could have been here which means the point q i i would be choosing here

So that is what i meant by all other rays a ray could as well be incident here then the point q would be here

So this point q is arbitrary and we will get a relation which does not depend on q and therefore it is sufficient for us to pick any two rays and get the image similarly if i look at the image image formation in a with a convex mirror then here is the first ray travelling along the principal axis which gets reflected here the secondary i have chosen a second ray to be incident here which gets reflected following the law of reflection here and both these rays appear this way and this ray appear to come from a common point i which is the image point and in this case again i is a virtual image now we discussed the image due to image due to a point object but in practice we look at extended objects in practice objects are extended objects extended objects point objects is a object is a zero dimensional object but a laterally extended object for example if i take an arrow like this

So this is an one d object one dimensional object a line object basically we have shown an arrow but it is basically a line

So it is a one d object if i take an object like this

So this is a 2d object

So 2d object if i consider a 3d object for example let me try to draw a cube

So the object could be a 3d object

So a three dimensional object of course what i have drawn are regular objects but there could be an arbitrary object an object of arbitrary shape which is a 3d object but of arbitrary shape we first discuss with discuss some of the regular objects and image formation due to regular objects the first step would be to discuss image formation due to a 1d object that is we have discussed a point object now let us look at a line object a line object which means it comprises of many many points here

So every point rays are emitted or rays come out from every point on this here

So if we can locate the corresponding image point for every point here then we would be able to locate the object the image of the object after reflection

So we will discuss formation of this extended formation of this images in the next lecture you