What is a Telescope?

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I'm sure if you were to grab a random group of people and ask them the question:

"***What* is a telescope?**"

you'd get varying degrees of responses. Most people would probably convey the idea that they make small objects look bigger, or more correctly they make distant objects seem closer. Perhaps also correctly, they'd say telescopes make dimmer objects appear brighter, and the idea that lenses of mirrors are involved is likely to be expressed too. You might even hear about radio or ultra-violet telescopes which don't even detect visible light, but most people (including myself) would probably just refer to "optical telescopes". (The odd person might try to be clever and start telling you about "telescoping sums" but that's far beyond the *scope* of what I'd like *focus* on).

Etymologically, a telescope is quite simple.

- "**Tele-**" = Far off / operating of a distance
- "**-scope**" = To look / to observe

So quite literally, a telescope is anything which lets us "observe" over a "large distance". But really this is only answering the question of "***what* does a telescope do?**" The other half of the question is "***how* does a telescope work?**" and "***why do telescopes exists?***" To really understand that we need to take a journey through history and look at how some of the greatest minds set out to appease their curiosity by observing the depths of the night sky, as well as (of course) using maths to understand the underlying principles of optics.

What do we use to bend light?

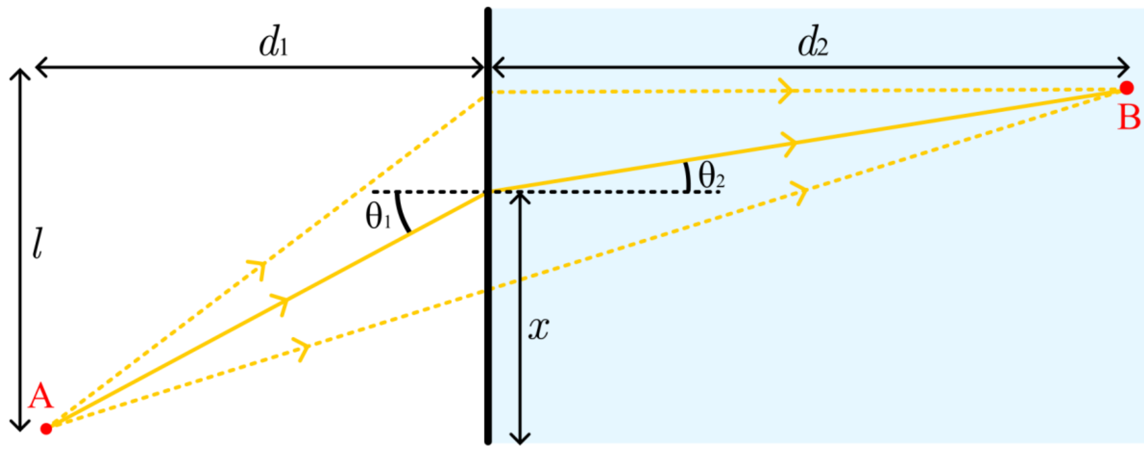
The answer is simple, a **lens** or a **mirror** (as you might have guessed). But *how* exactly do they wor*k*?

How does a Lens work?

In simple terms a lens is a thin piece of (usually) glass which bends light rays towards each other or away from each other. I always took this as a given, but the more I've thought about it the more it feels like that really isn't obvious. To really understand lenses, we need to start by understanding "refraction" i.e. the bending of light as it changes speed.

Suppose a light ray is travelling from a point A to a point B. However, part the way along the journey there is a boundary to a different material (medium). Initially, light travels at a speed v_1 and afterwards at a speed v_2. "Fermat's principle" says that light follows the path which takes the least time, so we ask:

"Which path should the light follow to minimise the time taken from A to B?"



[Figure 1 – Refraction and Snell's Law]

We can now find an expression for the time taken to travel from A to B along the middle path in **Figure 1**:

$$T = \frac{\sqrt{d_1^2 + x^2}}{v_1} + \frac{\sqrt{d_2^2 + (l - x)^2}}{v_2}$$

(Using Pythagoras and $time = \frac{distance}{speed}$)

Those of you who have met calculus, will know if we want to minimise / maximise a function we need to find its stationary points. As we vary x we want to see where T attains it's minimum, so we set the derivative (with respect to x) equal to 0 .

$$\Rightarrow \frac{dT}{dx} = \frac{x}{v_1 \times \sqrt{d_1^2 + x^2}} + \frac{-(l - x)}{v_2 \times \sqrt{d_2^2 + (l - x)^2}} = 0$$

But we know that sine is given by the opposite side divided by the hypotenuse so,

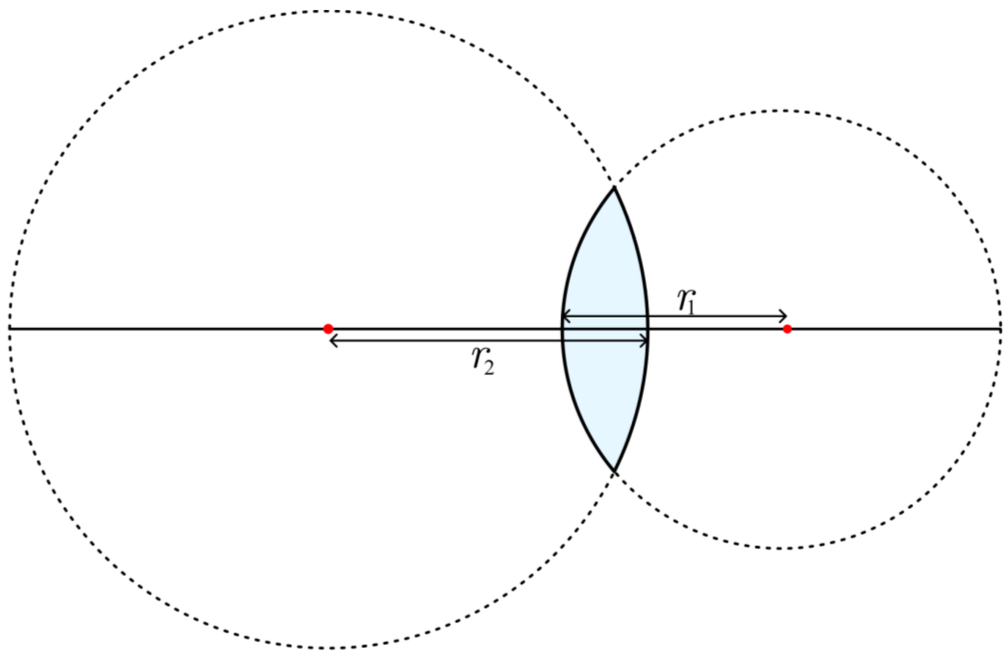
$$\Rightarrow \frac{dT}{dx} = \frac{\sin(\theta_1)}{v_1} - \frac{\sin(\theta_2)}{v_2} = 0$$

$$\Rightarrow \frac{\sin(\theta_1)}{v_1} = \frac{\sin(\theta_2)}{v_2}$$

This result is known as **Snell's Law of Refraction** (more commonly stated as $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$, where $n = \frac{c}{v}$ is the "refractive index" of a material and c is the speed of light in a vacuum) and this law governs how a lens works.

A lens consists of 2 such boundaries, however they are curved rather than flat. When dealing with a lens system we make two assumptions:

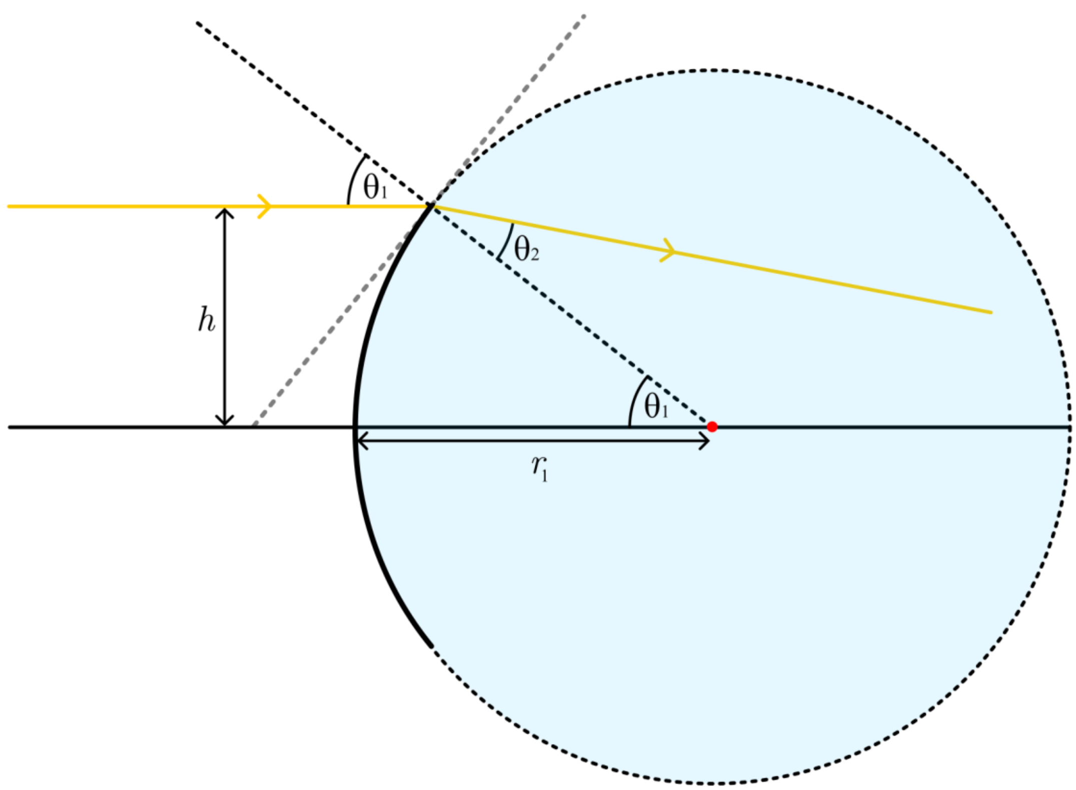
- The lens has negligible thickness i.e. it's a "thin lens"
- All angles are small so the small angle approximation, $\sin(\theta) \approx \tan(\theta) \approx \theta$ holds true i.e. Snell's Law becomes $n_1\theta_1 = n_2\theta_2$



[Figure 2 – Thin lens (Convex / Converging)]

Figure 2 shows what a "thin lens" looks like. However, in dotted lines each boundary has been extended to form a circle. The radius of this circle is known as the "radius of curvature" of the boundary and is considered to be negative if is to the left of the arc (e.g. here r_2 is negative). The central line is called the "principal axis."

When talking about telescopes, we can assume that light rays from distant objects are all parallel to each other so let's see what happens when parallel light rays meet the lens!



[Figure 3 – First boundary of a thin lens]

We will first look at what happens at the first boundary of the lens which has been isolated in **Figure 3**. All angles are measured from the "normal line", the line perpendicular to the boundary's surface, which (if you remember your GCSE circle theorems!) also passes through the centre of our "imaginary" circle.

If the ray strikes the boundary at a height h above the principal axis,

$$\theta_1 \approx \sin(\theta_1) = \frac{h}{r_1}$$

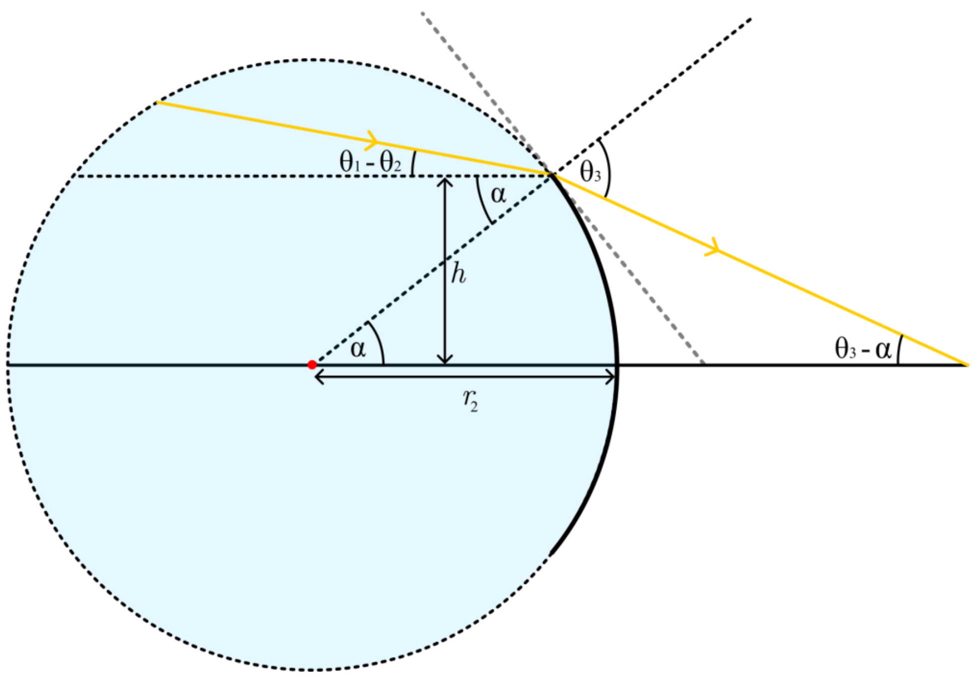
And Snell's law says that,

$$n_1\theta_1 \approx n_2\theta_2$$

Combining the two equations together we get that,

$$\theta_2 = \frac{n_1}{n_2} \times \frac{h}{r_1} = \frac{n_1 h}{n_2 r_1}$$

Also note the angle this new light ray makes with the principal axis is now $\theta_1 - \theta_2$ which will be important for the second boundary.



[Figure 4 – Second boundary of a thin lens]

Since we assumed the lens has negligible thickness the ray will strike the second boundary (shown in **Figure 4**) also at a height h above the principal axis.

$$\alpha \approx \sin(\alpha) = -\frac{h}{r_2}$$

(The minus comes from the sign convention on r_2 being negative)

And Snell's Law says that,

$$n_2(\alpha + \theta_1 - \theta_2) \approx n_1\theta_3$$

Finally combining all our results together, we get that,

$$\theta_3 = \frac{n_2\left(-\frac{h}{r_2}+\frac{h}{r_1}-\frac{n_1 h}{n_2 r_1}\right)}{n_1} = \frac{n_2}{n_1}\left(\frac{h}{r_1}-\frac{h}{r_2}\right)-\frac{h}{r_1}$$

And hence the angle between the final light ray and the principal axis is,

$$\theta_3 - \alpha = \frac{n_2}{n_1}\left(\frac{h}{r_1}-\frac{h}{r_2}\right)-\left(\frac{h}{r_1}-\frac{h}{r_2}\right) = \frac{n_2-n_1}{n_1}\left(\frac{h}{r_1}-\frac{h}{r_2}\right)$$

And finally, we can calculate the distance between the lens and the point at which the light ray meets the principal axis (the so called "image distance," v)

$$\theta_3 - \alpha \approx \tan(\theta_3 - \alpha) = \frac{h}{v}$$

$$\Rightarrow v = \frac{h}{\theta_3 - \alpha} = \frac{n_1}{n_2 - n_1}\left(\frac{1}{\frac{1}{r_1}-\frac{1}{r_2}}\right)$$

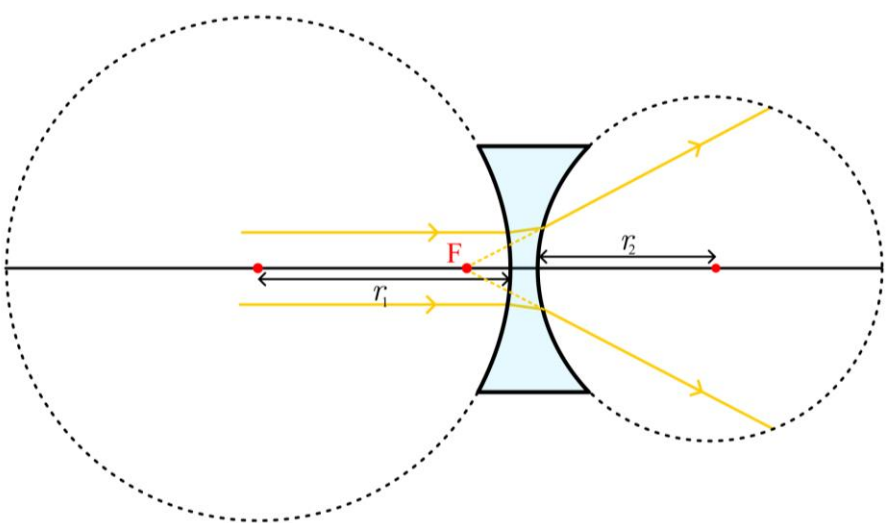
But do you notice something? This distance v is only dependent on the refractive indices and the radii of curvature, not on the height (or angle) the original light ray entered at. That is,

Any light ray parallel to the principal axis, no matter where it meets the lens, will be focused to the same point, the focal point!

This is a special type of image distance called the "focal length" f which occurs when the object is infinitely far away (so the object distance $u = -\infty$ using the sign convention that lengths to the left of the lens are negative) but the general result (left as an exercise for the reader to prove) is:

$$\frac{1}{v}-\frac{1}{u} = \frac{1}{f} = \frac{n_2-n_1}{n_1}\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$

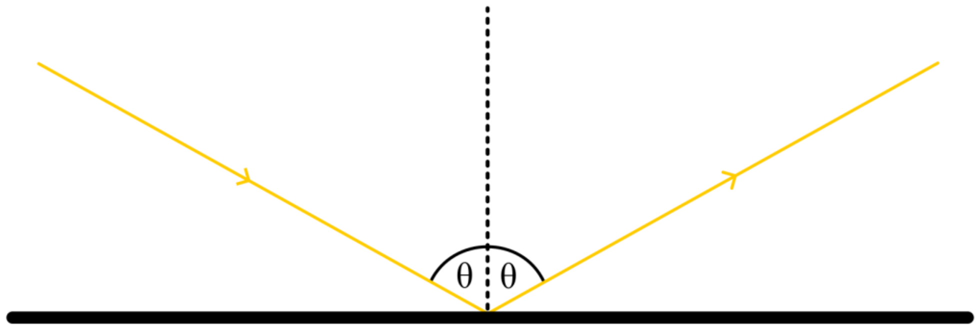
We now know that we can use lenses to focus light to a single point. So far, **Figures 2**, **3** and **4** have shown "**convex / converging lenses**" but choosing the first radius of curvature to be negative and the second to be positive produces a "**concave / diverging lens**" (illustrated in **Figure 5**), which as the name suggests bends light rays away from each other (and instead has a "virtual" focal point to the left of the lens)



[Figure 5 – Concave / Diverging Lens]

How does a Mirror work?

Contrary to lenses, the idea of a flat mirror feels fairly intuitive, any ray of light which strikes a flat mirror at a certain angle will be reflected back at that same angle as shown in **Figure 6**.

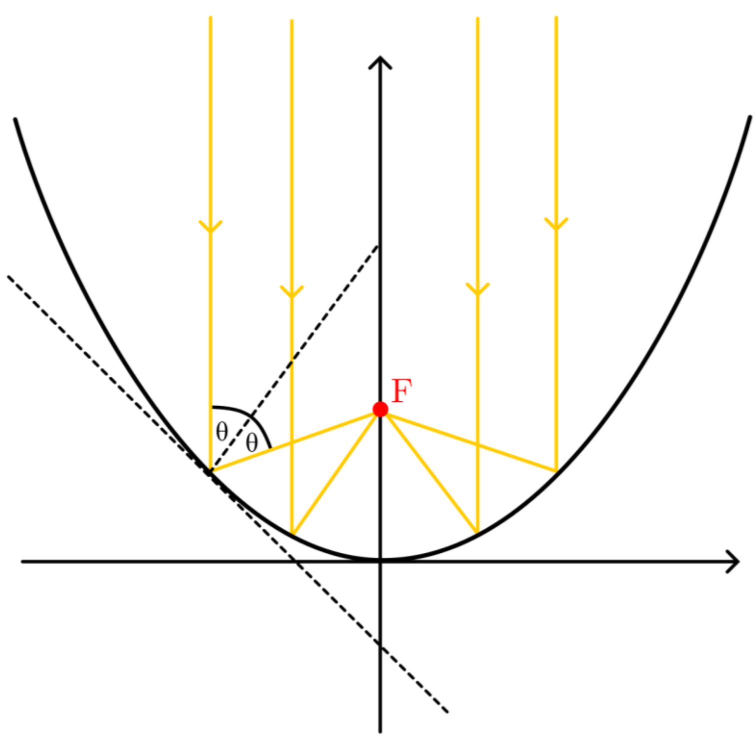


[Figure 6 – Flat mirror]

However, as we said before, when it comes to telescopes light rays arriving from distant objects are effectively parallel. This means a flat mirror isn't of much use to us because we need to focus light to a point. But now the question is:

"What shape of mirror focuses parallel light rays to a point?"

Well, let's imagine a coordinate grid. The light rays are travelling downwards parallel to the y -axis and strike a (concave) mirror of shape $y = f(x)$ passing through $(0,0)$ and focusing to a point F on the y -axis.



[Figure 7 – Mirror focusing light to a point]

Hmm, the diagram looks awfully "quadratic-like" doesn't it? Consider the left most light ray on **Figure 7**. Zooming in on the point where the ray strikes the mirror, the mirror is effectively flat with its gradient being that of the tangent to $y = f(x)$ at that point (where $x = x_0$). That is, its gradient is $f'(x_0)$ (i.e. the derivative of the curve describing the mirror!)

Now let's suppose the normal to the curve at this point makes an angle of θ with the incident light ray (by recalling the negative reciprocal for normal lines).

$$\tan(\theta) = \frac{\Delta x}{\Delta y} = -f'(x_0)$$

But the reflected ray then makes an angle of 2θ to the incident light ray.

$$\tan(2\theta) = \frac{2\tan(\theta)}{1 - \tan^2(\theta)} = \frac{-2f'(x_0)}{1 - \left(f'(x_0)\right)^2}$$

And now we know the gradient of the reflected light ray so we can work out the equation of the reflected ray.

$$y - f(x_0) = \frac{1}{\tan(2\theta)}(x - x_0)$$

$$y - f(x_0) = \frac{\left(f'(x_0)\right)^2 - 1}{2f'(x_0)}(x - x_0)$$

$$y = \frac{\left(f'(x_0)\right)^2 - 1}{2f'(x_0)}x + \frac{2f'(x_0)f(x_0) + x_0 - x_0\left(f'(x_0)\right)^2}{2f'(x_0)}$$

Whilst this is a mess, we have a single expression for the coordinate of the y-intercept and since this is the focal point we want it to equal some constant a for all values of x_0. Re-writing $x = x_0$ and $y = f(x_0)$ to simplify the notation we have,

$$\frac{2\frac{dy}{dx}y + x - x\left(\frac{dy}{dx}\right)^2}{2\frac{dy}{dx}} = a$$

We've ended up at a (quite nasty) differential equation, but it turns out the solution to this equation is very simple, it is:

$$y = \frac{x^2}{4a}$$

That is, the shape of our mirror should be a perfect **parabola** (or in 3D a paraboloid), a shape you've likely seen in things like radio dishes! For those interested this is how we can find the solution to the differential equation:

$$\frac{dy}{dx} = u \;\Rightarrow\; dy = u\,dx$$

$$y = a + \frac{ux}{2} - \frac{x}{2u}$$

Taking the differential of both sides,

$$u\,dx = dy = \frac{\partial y}{\partial x}dx + \frac{\partial y}{\partial u}du = \left(\frac{u}{2} - \frac{1}{2u}\right)dx + \left(\frac{x}{2} + \frac{x}{2u^2}\right)du$$

$$\left(\frac{u}{2} + \frac{1}{2u}\right)dx = \left(\frac{x}{2} + \frac{x}{2u^2}\right)du$$

$$\Rightarrow \frac{dx}{x} = \frac{du}{u} \Rightarrow \ln(x) = \ln(u) + c \Rightarrow x = Au \Rightarrow y = a + \frac{x^2}{2A} - \frac{A}{2}$$

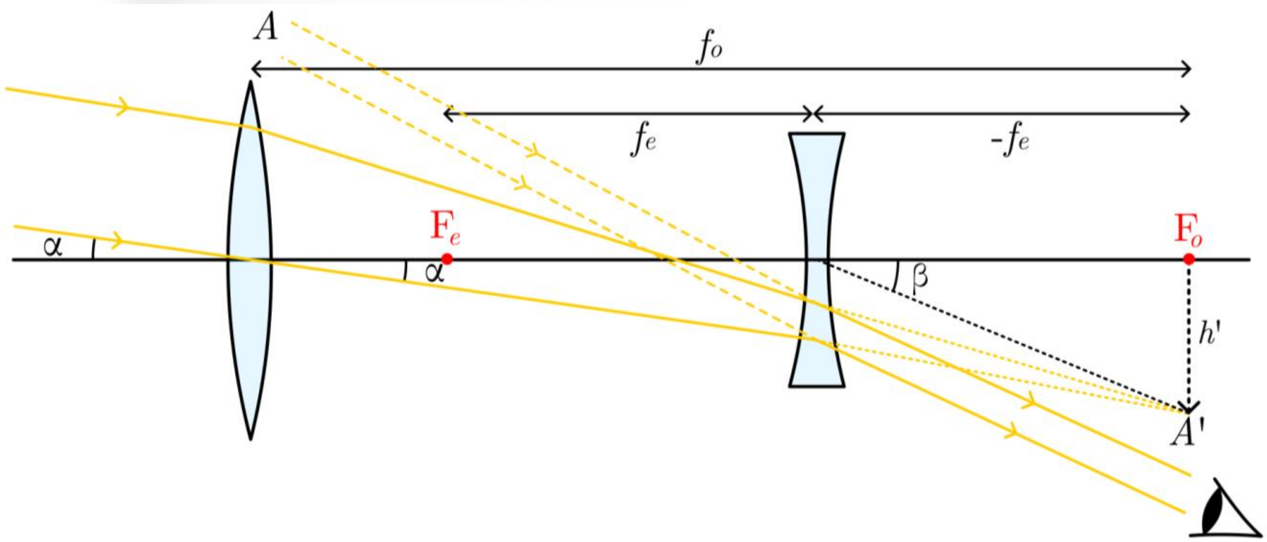
$$\textit{Since at } x = 0\,,\, y = 0 \textit{ we get that } A = 2a \Rightarrow y = \frac{x^2}{4a}$$

More commonly, we rotate the parabola by $90°$ to get, $y^2 = 4ax$ which has its focus at $(a, 0)$. Now, it's even more simple to diverge the light rays using a mirror than a lens. All you have to do is use the opposite (convex) side of the parabola and $(a, 0)$ becomes the virtual focal point.

How do we use optics to create telescopes?

The first few known telescopes began to appear in the early 1600s. The early designs were refracting telescopes, meaning they used lenses. In particular, they consisted of an "objective lens" followed by an "eyepiece lens", an idea which is still used in optical instruments today! Galileo used a convex objective lens and then a concave eye piece lens (a design now referred to as a **Galilean telescope**) but Johannes Kepler instead used convex eye piece lens. Let's explore the details of how these telescopes worked and see the reason Kepler made the modification he did.

What did Galileo do?



[Figure 8a – Reproduction of Galileo's Original Telescope]
[Figure 8b – Ray Diagram for a Galilean Telescope]

Figure 8b shows the details of how the telescope in **Figure 8a** works. Now, the first time I saw this diagram I was completely lost, so let's analyse it step by step.

The first thing we need to note is that the incoming light rays (2 rays are shown for simplicity) are parallel to each other but not necessarily parallel to the principal axis. After entering the (convex) "objective lens" if there was no other lens an image would form (shown using dotted lines) at the focal point of the objective lens, F_o since,

$$\frac{1}{v_1} - \frac{1}{-\infty} = \frac{1}{f_o} \Rightarrow v_1 = f_o \text{ i.e. image distance is } f_o$$

This is the "intermediate image" A'.

However, there is another lens, the concave "eyepiece lens" which diverges the light rays in such a way that they become parallel again, that is we need the image distance to be $v_2 = -\infty$ (Since the image A forms to the left of the eyepiece lens). Now the key is that the intermediate image A' acts as the object for the eyepiece lens so we can find the distance between the eyepiece lens and A' as follows,

$$\frac{1}{-\infty} - \frac{1}{u_2} = \frac{1}{f_e} \Rightarrow u_2 = -f_e \text{ (Note, } f_e \text{ itself is negative)}$$

That is, we need to place the eyepiece lens exactly one focal length, f_e to the left of the intermediate image.

Now we understand *what* is going on with the light rays, but *how* actually is this useful?

Recall the goal of a telescope. We are trying to make far away objects appear closer, but what does this *actually* mean. What we perceive as "size" is "angular size", in other words how large of an angle does an object take up in our "field of view" (FOV). When we "magnify" an object we are asking:

"How many times greater is the object's angular size in our field of view?"

Mathematically we can answer this by saying the magnification, m is given by:

$$m = \frac{\beta}{\alpha}$$

(Because the line through A' and the centre of the eyepiece lens is parallel to the emergent rays from the eyepiece lens assuming the image A is infinitely far away)

As always with lens systems, we can use the small angle approximations to get that,

$$\alpha \approx \tan(\alpha) = \frac{h'}{f_o}, \beta \approx \tan(\beta) = \frac{h'}{f_e}$$

$$\Rightarrow m = \frac{\frac{h'}{f_e}}{\frac{h'}{f_o}} = \frac{f_o}{f_e}$$

As **Figure 8b** suggests, the focal length of the objective lens is longer than the focal length of the eyepiece lens, which (thankfully) implies our image appears is magnified and appears larger!

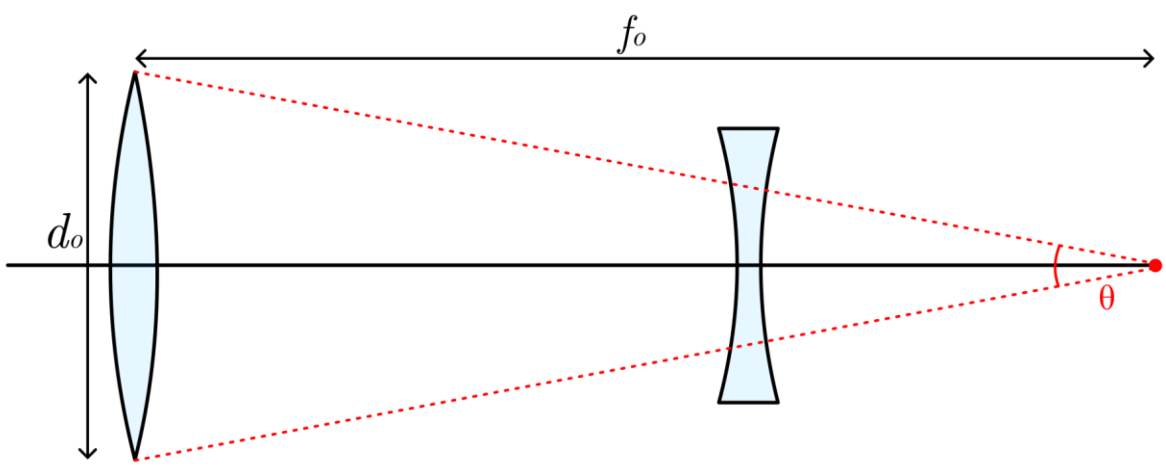
The second goal of a telescope was to make objects appear "brighter." Brightness is just a measure of how much light (energy) is striking a particular area per second. That is, it measures energy per unit area per unit time. The telescope can't change how much energy it receives every second, however it most certainly can concentrate that "power" into a smaller area. If D_o is the diameter of the objective element (in this case the "aperture") and D_{eye} is the diameter of your eye, assuming no light escapes, the brightness increases by a factor of:

$$\frac{\pi\left(\frac{D_o}{2}\right)^2}{\pi\left(\frac{D_{eye}}{2}\right)^2} = \frac{D_o^2}{D_{eye}^2}$$

And again, as we might hope, the diameter of the aperture is certainly greater than the diameter of an average human eye!

How did Keplar change Galileo's design?

Being one of the first designs of anything brings with it both novelty of genius but also many limitations and Galileo's telescope was no exception to this rule. I mentioned "field of view" (FOV) earlier but what does this mean mathematically.



[Figure 9 – Field of view of a Galilean Telescope]

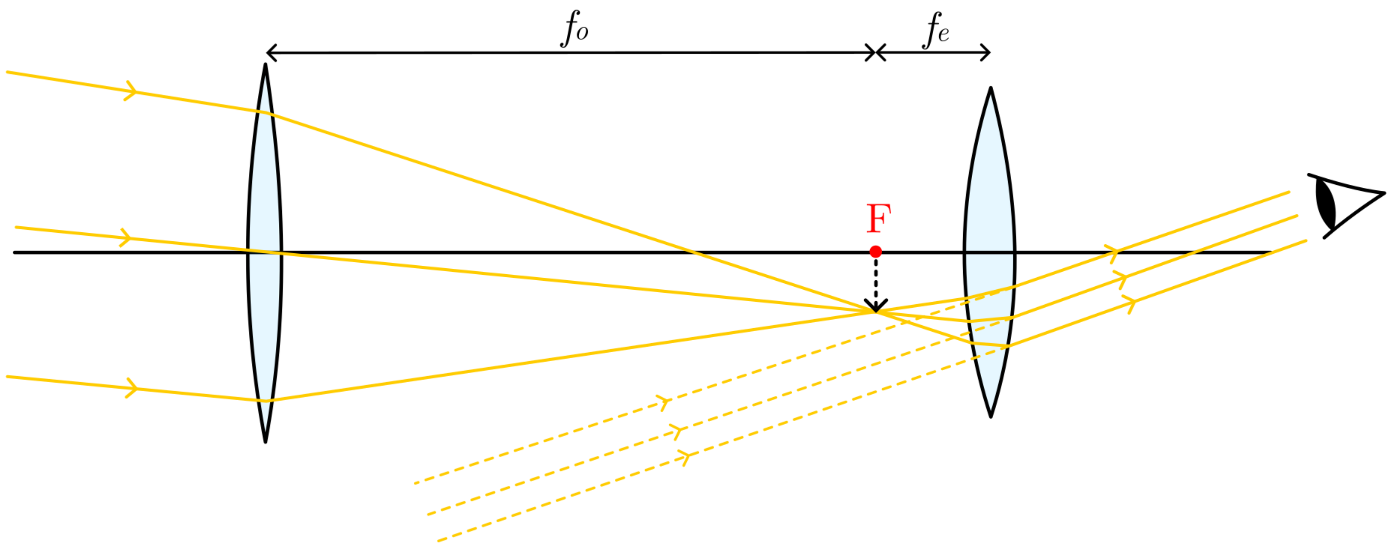
The diameter of our aperture is d_o and the focal length of the objective element is f_o. Looking at **Figure 9**, if we imagined light rays arriving at an angle steeper than the red dotted line, they would form an intermediate image outside the height of the telescope, which is definitely not allowed!

This means the telescope can only focus light rays which arrives at an angle within the red dotted lines, and this is precisely the field of view.

$$FOV = \theta = 2\tan^{-1}\left(\frac{d_o}{2f_o}\right) \approx \frac{d_o}{f_o}$$

So, the longer the focal length of the of the objective lens, the narrower the field of view. But recall before the magnification, $m = \frac{f_o}{f_e}$ so, we need a long focal length to provide a large magnification. This trade off highly limits the magnification we can reach with Galileo's design, not helped by the fact that the image becomes quite distorted around the edges (since the small angle approximations aren't perfect close to the edge of the lens).

To get around this Kepler made a simple change. He used a convex eyepiece lens, rather than a concave lens, so let's take a look at how this fixed (or at least improved) the FOV issue.



[Figure 10 – Ray Diagram for a Keplerian Telescope]

All the equations and principles describing the "**Keplerian telescope**" are almost identical to the Galilean telescope with the only difference being where the objective lens focuses.

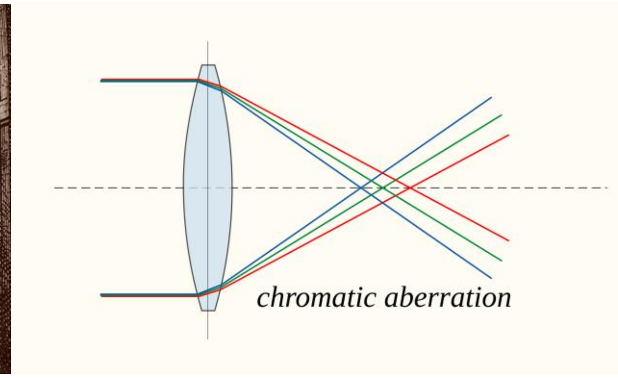
We can see in **Figure 10** that the "intermediate image" is formed between the objective lens and eyepiece lens, so the focal length of the objective lens can be shorter than the length of the telescope. Also, using two convex lenses produces less distortion.

However, you might notice the light ray which came in from the top is now at the bottom, so the image is upside down! Luckily when observing stars and planets this isn't too big of an issue.

What is a bigger issue on the other hand is just how long telescopes were getting. In order to get a large enough magnification and minimise distortion, the focal length of the objective lens must be extremely long. Unfortunately, this is an issue intrinsic to refracting telescopes, so a solution was needed.

How did Isaac Newton (unsurprisingly) get involved?

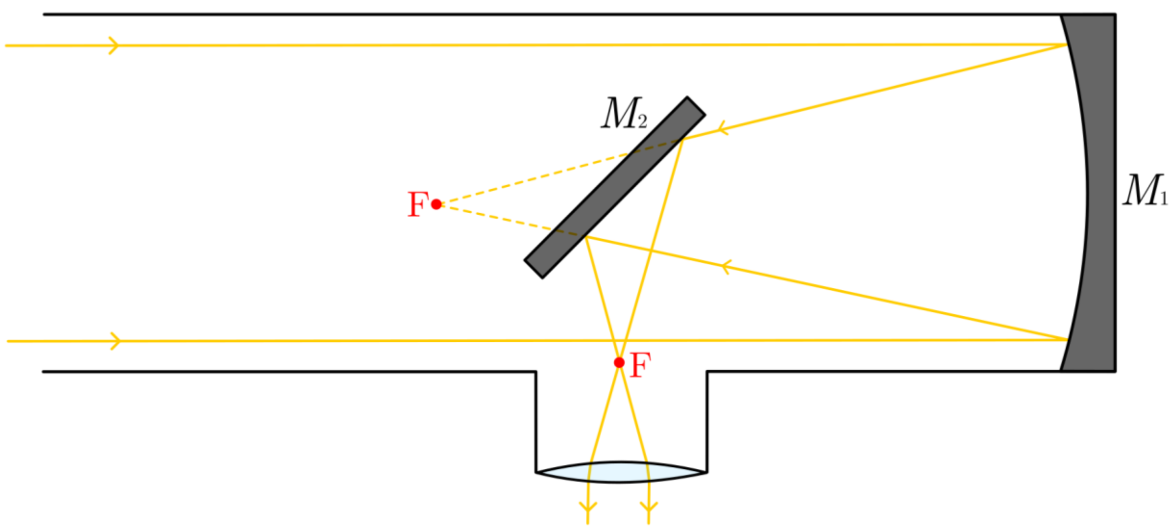
One of the many things Isaac Newton is accredited with is his experiment of separating white light into the entire spectrum of colours using a prism. This is because different wavelengths (i.e. colours) of light have slightly different refractive indices, so the shorter wavelengths of light refract more than the longer wavelengths and get separated.



[Figure 11a – Illustration of Isaac Newton separating white light with a prism]
[Figure 11b – Chromatic Aberration]

Now notice that close to the ends of a lens, the shape looks a lot like prism and indeed white light close to the edges of a lens can be separated into its colours (as we can see in **Figure 11b**); an effect known as "chromatic aberration." This causes "rainbowing" effects around the edge of the image which is another limitation of lenses.

Luckily Newton had a solution! The "**Newtonian telescope**" which used mirrors rather than lenses.



[Figure 12 – Ray Diagram for a Newtonian Telescope]

Again, the light rays shown in **Figure 12** enter from the left and are parallel to each other. They first strike mirror M_1 which tries to focus the light to a point at F . As we established before this mirror must be a paraboloid in shape. However, before the light is focused, it strikes mirror M_2 angled at 45° and passes into an eyepiece lens (or a camera) to make the light rays parallel again.

Similar to the refractor telescopes using a shorter focal length eyepiece lens provides a greater magnification but a narrower FOV.

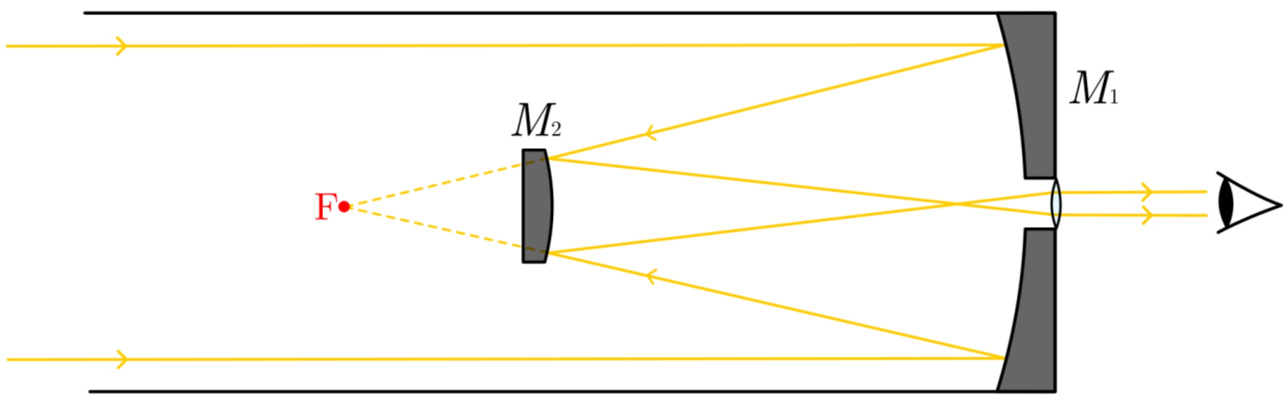
Hopefully you can see that Newtonian telescopes are much more compact since light doesn't just travel in one direction down the tube of the telescope. They often also have a wider aperture so can let in more light since larger lenses are extremely difficult to make (compared to mirrors). Finally, since most of the optical components are mirrors, the effects of chromatic aberration are greatly diminished.

What Telescope designs get used today?

Even if you aren't interested in telescopes, you've likely heard of either:

"The James Webb Telescope" or "The Hubble Space Telescope"

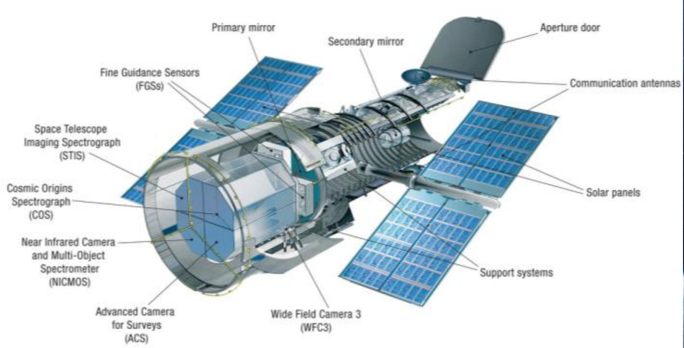
These could both themselves warrant their own entire essay about the exact details of their operation and the importance of their discoveries but for this essay all we care about is their design. Both of these telescopes are based on the "**Cassegrain reflector**" telescope.

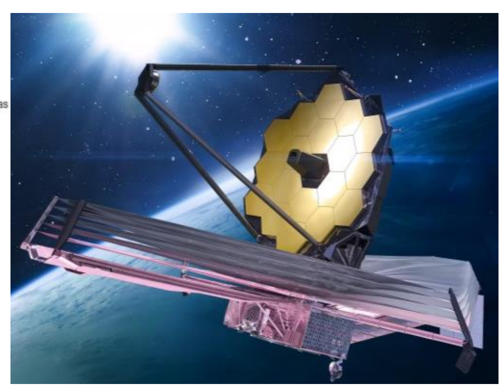


[Figure 13 – Ray Diagram for a Cassegrain Telescope]

Several variations on the basic Cassegrain reflector (illustrated in **Figure 13**) have been designed (some using both lenses and mirrors known as catadioptrics) but the basic design uses a concave parabolic primary mirror (as before) followed in fact by convex hyperbolic mirror (to balance aberrations).

Similarly to the Newtonian telescope, M_1 is the parabolic mirror, but it contains a small hole at its centre where the eyepiece lens is located. The mirror M_2 rather than being angled and flat, is parallel to M_1 and curved slightly to diverge the light rays slightly into the eyepiece lens (or a camera) for viewing the image.





[Figure 14a - Hubble Space Telescope (HST)]
[Figure 14b - James Webb Space Telescope (JWST)]

Hopefully now you can see the connections between the design of the HST and JWST in **Figure 14** with the diagram of the Cassegrain reflector telescope!

What about the "Liquid Mirror Telescope"?

One thing you might have realised by now is that … well,

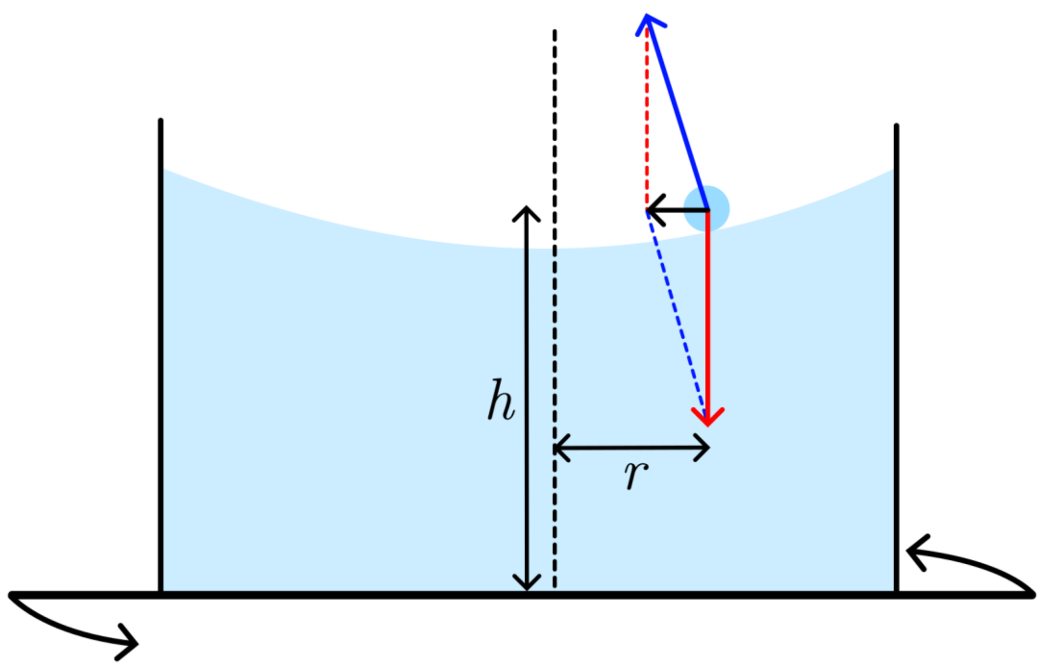
Telescopes are complicated.

Not only are they complex from a theoretical perspective, but also in terms of manufacturing. Any micro-imperfection in the surface of a lens or mirror can cause a telescope to completely stop working. For a mirror to attain a precise focal point, we showed it must be perfectly parabolic. Luckily, we can turn to the nature and the laws of physics to find parabolas (and paraboloids)!

Imagine a glass of water. Place this imaginary glass of water at the centre of a turn table so it starts rotating about its central (longest) axis.

"What happens to the shape of the surface of the water?"

Given how much I've hinted at it, it doesn't exactly take a genius to guess that the surface of water forms a paraboloid. But what's the reason?



[Figure 15 – Rotating glass of water on a turn table]

Once the turntable is rotating at a constant a "angular velocity" ω (i.e. the angle swept out per second is constant) the surface of the water will be in equilibrium.

Let's consider a small packet of water a height h above the bottom of the container and a distance r from the centre (taken to be positive to the right), with a mass of m as shown in **Figure 15**.

Downwards force (red arrow) = Weight = mg

(g = acceleration due to gravity)

At equilibrium the water isn't accelerating up or down, so there is no resultant upwards force. Note that the buoyancy force (blue arrow) acts perpendicular to the surface of the water. Perhaps we can use this to find the gradient of the surface of the water?

$$\text{Resultant force (black arrow) = "Centripetal Force"} = m\omega^2 r$$

("Centripetal force" is the force directed towards the pivot required for circular motion)

But we can use these together to work out the gradient of the buoyancy force (normal to the water surface),

$$\text{Perpendicular gradient} = -\frac{mg}{m\omega^2 r}$$

$$\Rightarrow \text{ Gradient} = \frac{dh}{dr} = \frac{m\omega^2 r}{mg} = \frac{\omega^2 r}{g}$$

$$\Rightarrow \int dh = \int \frac{\omega^2 r}{g} dr$$

$$\Rightarrow h = \frac{\omega^2}{2g} r^2 + h_0$$

Where, h_0 is the height at the centre of container. But look! The height h depends on r^2 which is precisely the equation of a parabola. Furthermore, the focal length f of the parabola can be found since,

$$4f = \frac{2g}{\omega^2} \Rightarrow f = \frac{g}{2\omega^2} \text{ (Using the } y^2 = 4ax \text{ form of a parabola)}$$

Now all we have to do to make this into a telescope is replace the water with liquid metal and use a much larger container (even up to 6m in diameter) et voila, we have ourselves a perfectly parabolic primary mirror (as shown in **Figure 16**). Pure genius!

[Figure 16 – Liquid Mirror Telescope being used for a primary mirror with a rotating sensor]

Why telescopes?

In the introduction of this essay, I promised we'd answer the "*what,*" "*how,*" and "*why*" questions about telescopes. Whilst up to this point, I've said the word "*what*" 20 times and the word "*how*" 22 times (assuming I can count), the only times I've said "*why*" have been in this paragraph and the introduction.

So *why*? Throughout humanity's past one of the only things, we have always had is the ability to view the sky. I mean, in some ways the better question is, *why not*? If I've done my job correctly with this essay the *why* should have answered itself; telescopes are absolutely genius! And even if somehow you haven't been convinced, hopefully now, if you ever get asked "***what is a telescope?***" you'll know what to say.

Additional Information, References and Links:

All diagrams are my own, references are provided for any images used below.

- **Figure 8a** - Powerhouse.com.au. (2023). Powerhouse Collection - *Reproduction of Galileo's telescope*. [online] Available at: https://collection.powerhouse.com.au/object/390728 [Accessed 9 Mar. 2025].

- **Figure 11a** - Ball, P. (2023). *'Refraction is then all there is to it': How Isaac Newton's experiments revealed the mystery of light*. [online] livescience.com. Available at: https://www.livescience.com/physics-mathematics/refraction-is-then-all-there-is-to-it-how-isaac-newtons-experiments-revealed-the-mystery-of-light [Accessed 11 Mar. 2025].

- **Figure 11b** - Wikipedia Contributors (2019). Chromatic aberration. [online] Wikipedia. Available at: https://en.wikipedia.org/wiki/Chromatic_aberration [Accessed 14 Mar. 2025].

- **Figure 14a** - HubbleSite. (2025). Hubble's Instruments Including Control and Support Systems (Cutaway). [online] Available at: https://hubblesite.org/contents/media/images/4521-Image [Accessed 16 Mar. 2025].

- **Figure 14b** - ig.space. (n.d.). Overview of the James Webb space telescope. [online] Available at: https://ig.space/commslink/overview-of-the-james-webb-space-telescope [Accessed 16 Mar. 2025].

- **Figure 16** - Wikipedia. (2023). Liquid-mirror telescope. [online] Available at: https://en.wikipedia.org/wiki/Liquid-mirror_telescope [Accessed 16 Mar. 2025].

I plan to make a video on this topic of telescopes, as well as many other topics in the future on my YouTube channel, PolyaMath: https://www.youtube.com/@Polyamathematics