I'd like to own a telescope

Why?

A telescope lets me see more than I can with the naked eye – much more. The first thing I notice when pointing a telescope at the starry sky, pointing it almost anywhere really, is that the gaps between the stars are seen to be populated with yet more stars I can't see with my naked eye. The great expanse of the universe suddenly seems even greater; I feel more that I'm part of something really big. Are we really just a speck in the vastness of space? It's one thing to look at pictures of star fields but another seeing them with our own eyes. Some parts of the sky are better populated with stars than others and the best places to look for more stars with a modest instrument are *open clusters*. Pictures on the web or in books of *globular clusters* and *galaxies* look more impressive but one needs the aid of astrophotography to get the best out of an amateur telescope pointed towards these.

Another aspect of stars to anyone looking through a telescope is that they have more varied colours that we normally think stars have. There's a good reason for this. Starlight is faint and the amount that gets through our eye pupils at night is just enough to be seen by our night vision sensors, the rods of our eyes' retinas. Rods produce uncoloured images. Our colour vision comes from our daylight sensors, the cones, and only a few of the brightest stars give us enough light to produce a sensation of colour. For example, *Aldebaran*, the brightest star in the northern hemisphere of the sky, looks conspicuously red; *Sirius*, the brightest of all visible stars, looks whiter than the average star but all in all we don't think of the stars as richly coloured. Yet the colour of a star is in fact an important property that gives us a pretty direct measure of its temperature. An amateur telescope of 200 mm diameter has 25 times the diameter of our eye pupils at night, or over 600 times the area. Even allowing for some loss of light in the telescope, the image of a star in this telescope will be formed by at least 500 times the amount of light that gets unaided into the eyeball. This is enough to stimulate the cones into producing coloured images of many more stars.

The figures above also let me estimate how faint are the faintest objects my telescope can show me when I look through it. A factor of 500 in the amount of light corresponds to a magnitude (m) difference of 6.75 on the stellar scale. If I could just see objects of magnitude 6 with my naked eye (good enough to see the planet Uranus faintly in a dark sky site), then about the faintest I'll see though a 200 mm telescope is magnitude (6 + 6.75) or about 12, or 13 if I'm are lucky. There is no chance, for example, of seeing Pluto, which has an apparent magnitude about 15, or any of the trans-Neptunian objects that come into the news these days. If I look in the right place, I should have no trouble seeing the dwarf planet Ceres, which has an apparent magnitude of about 8, typically. With a sensitive camera attached to my telescope that can accumulate an exposure over many tens of seconds, then I'll do much better at seeing faint objects, unless there is too much artificial light in the sky.

The stars are just points of light to the naked eye and are still points of light in a telescope (albeit spread out a bit due to the optics of telescope and eye). Planets, though, show their size in a telescope. To the naked eye, Mars is typically the same size as a golf ball held up at least one kilometre away, little more than an orangey dot in the sky. With a magnification of 100, Mars becomes the size of a golf ball held up some 10 metres away, big enough to see the icecaps and hints of features, all be it the image probably shimmers a bit in the atmosphere. The giant Jupiter is bigger than Mars in the telescope. Its banded atmosphere can be made out. The Galilean moons are clearly seen in a short line near the planet, sometimes 4, sometimes 3 when one is hidden behind the planet. Saturn's rings are clear when the seeing is good, but still tiny compared with photographs in books or on the web. Saturn is always over a thousand million km distant so perhaps that's hardly surprising. None of this detail can be seen with the naked eye.

Distance, though, is not the only gauge of the telescope's power. The nearest and most commonly seen of all night-time sights is the Moon. To the naked eye it is a flat, mottled crescent, enlarging to a bright disc at full-moon. Through the telescope it is a three-dimensional world of craters, mountains, rills and plains, never the same in appearance from one day to the next, a world both alien and yet more closely connected to the Earth than any other. The Moon is the beginning of a journey into space and it seldom fails to impress when seen through a telescope.

There's more in the sky than stars and planets. Among the other things are 'deep sky objects'. Messier first catalogued some of the conspicuous ones in the late 18th century. His catalogue includes objects that would later be identified as *galaxies*, *gas clouds*, *planetary nebulae*, *globular* and *open clusters*. Again, the telescope shows what the eye can't see. Nowadays most amateurs will get a better view of the Messier objects than Messier himself could with his comparatively small telescope. Today's extended catalogue for amateur astronomers is the book of Caldwell objects, compiled by Patrick Moore (whose full name was Caldwell-Moore).

Looking is only the beginning. There's much more I can do with a telescope once I become more experienced. Amateurs now take electronic pictures that professionals would have been proud of only a few decades ago. With electronic attachments, the amateur can engage in serious study of stellar spectra or the changing brightness of variable stars; the amateur can measure light curves of eclipsing binary stars. The amateur can do what amateurs have done almost better than professionals, namely look for the unexpected: nova or even supernova that have flared up without warning, comets that have been spotted in the outer reaches of the solar system and found to be heading towards the Sun, or keeping track of asteroids.

Before you talk about telescopes, what about a pair of binoculars?

OK, there really are many reasons for wanting a telescope (and I didn't mention solar observations). What choices must be made? The first is to consider a pair of binoculars.

Binoculars are really portable, can easily be taken into the country on an excursion, or with you on holiday or just taken to the garden, or put in rucksack and taken down to the beach where it's darker than in the street. During the day you can use them for bird-watching, following sport or whatever. Binoculars are good for the wide view. They are excellent for the Moon, for open clusters, for seeing more stars and for asterisms (groups of stars within constellations), for the moons of Jupiter, for seeing stars in suburban light that you can't see with your naked eye but should have been able to see if the sky were dark.

Binoculars come with two numbers attached, like 8×25, 10×50, etc. The first is the *magnification*. The greater the magnification the harder they are to hold steady. A constantly shaking image is not going to add to your enjoyment. I'd choose a magnification of about 10 or 12 and even then it normally helps to steady your arm on a post, a wall, a window or anything convenient. Magnifications of 15 or more will need a tripod assist but that makes the whole operation of using the binoculars more cumbersome. Broadly speaking, the greater the magnification the less the field of view but for a given magnification a more expensive pair may offer a bigger field of view. You'll likely have to look into the detailed specification to find the actual field of view. As a yardstick, the full moon is half a degree wide. My ×10.5 binoculars (an odd size) have a 6º field of view, which is quite wide. It is the combination of using both eyes with magnification and a wide field of view that gives binoculars that 'wow' factor, more so than you get through many telescopes where the much larger magnification generally used comes with a much reduced field of view.

The second number associated with binoculars is the *width of the objective lens* (the big light-gathering lens at the fatter end) in mm. This clearly determines the light grasp of the binoculars but the key figure to work out is the second number divided by the first. E.g. for 10×50 binoculars this is 5 and it represents the width in mm of the '*exit pupil*' of the binoculars. To make full use of your eye, the binocular exit pupil should match the size of your eye pupil. This is about 7 mm when you are looking at the stars. So 10×50 binoculars will not quite fill your eye with light. Clearly 10×70 would do but they will be larger, heavier and perhaps twice as expensive so you may decide that 10×50 are a decent compromise. I'd say don't go for a smaller number than 4 after you've divided the objective diameter by the magnification. These would be fine for daylight viewing when your eye pupil may be just 2.5 mm in diameter but the image they give at night will seem dim.

So much for the fundamentals. Though there is a huge range of binoculars out there, many are not great for astronomy. Stars are the hardest of all objects to image sharply. Poorer lenses may give an image decent enough for watching a fast moving sport in the distance but they will fail to give a pin-point image of a star no matter how the focus is adjusted. Another defect that star images show up conspicuously is *chromatic aberration*. This is a failure of different colours in the spectrum to be in focus all at the same place. The result is that your star images will have coloured fringes. This effect can be reduced but not eliminated by good lens design. *Low dispersion* is a relevant buzzword worth looking for in the binocular description. Unfortunately our own eyes have their own quite substantial chromatic aberration, the effect of which is normally hidden in the images we see but which bright stars of light show up. In a shop it's not that easy to test the quality of a point image even though you have the binoculars in your hand. You can make sure, though, that there is independent focusing for left and right eyes. This is usually achieved by having a focusing knob that changes the focus for both eyes at once and a separate adjustment on the right eye lens. You focus the left eye image with the knob and then any correction for the right eye image with the separate adjustment.

There's a point worth making with binoculars that is often missed. You hold up the binoculars and look through them, obviously. What isn't obvious is that there is an optimum distance to hold the binoculars in front of your eye to get the widest and most comfortable field of view. This distance is such that the exit pupil of the binoculars coincides with the pupil of your eye. A few mm either way and you will find the field of view narrows considerably and is unsteady. This optimum distance should coincide with resting the binoculars on your eyebrow ridge. If it coincides with holding the binoculars out in space in front of you then your arms will very quickly get tired. If you have to jam the binoculars right into your eyes for the best view, that's very uncomfortable. My binoculars have rubber caps at the end of the eyepieces on twisting tubes whose distance can be adjusted in or out so that the soft cap can rests on my eye ridge when the binoculars are at the right distance for the recess of my eyes. These tubes don't affect the focusing, for they don't house the eyepiece lens. Some such arrangement is highly desirable for astronomical use when you will be looking up in the air a lot. The caps also block out quite a bit of stray light from any nearby house or street light. Most spectacle wearers should be able to adjust the binocular focus so that they see clearly without their spectacles. The binocular eyepieces do the work of the spectacles unless you have bad astigmatism or more complex eye problems.

That's not quite the end of what it's worth saying about binoculars. Most binoculars have coated lenses. The original purpose of coatings was to reduce unwanted reflections from the lens surfaces and increase their transmission. This is good. The better binoculars have internal lenses coated as well as the external ones you can see. More recently, coatings have been added to some models allegedly to improve the contrast for wildlife or other specialist viewing in the manner than a photographer might use a coloured filter. These block some of the incident light, which is detrimental for astronomical use. The general advice on the web is to avoid binoculars with ruby-red coatings. My own supplemental advice is to keep the lens caps on your binoculars when they are not in use. They reduce the risk of scratching the lenses, getting dust on the lenses and degradation of the lens coating.

You'll see much more in the starry sky with binoculars than with the naked eye. I suspect that most 'serious' amateur astronomers who own sophisticated telescopes also have a favourite pair of binoculars close at hand. If you do get binoculars before getting a telescope, you're not likely to ditch them later. What make should you get? Quite frankly I haven't the experience to offer detailed advice. Manufacturers like Celestron and Meade specialise in astronomical optics. The Olympus DPS1 10×50 at around £50 as I write is well thought of. I've also had the Pentax 10×50 pcf wp ii recommended to me at around £130. Some extended web browsing is worth it and you could do worse than start at http://binocularsky.com/ where you will find aspects discussed that I haven't mentioned and some model suggestions in various price ranges.

Let's get back to telescopes.

What does a telescope do?

I think most people would say that a telescope magnifies. However a star is a dot in the sky, in reality an incredible small dot. Magnify an incredibly small dot by ×100, or even ×1000, and it is still an incredibly small dot. In some telescopes stars will look like little discs but the disc is an artefact of the telescope optics and your eye. The disc isn't a magnified image of the star. If a star were shaped like a tortoise, its image would still be a disc. If you pause to think about this it shows how vast the universe must be. A star like our Sun is big, about 1.4 million km in diameter. Yet the nearby stars beyond the Sun are about 10^{14} km away, 100 million, million km. The distance away of even nearby stars is therefore some 100 million times their diameter. No wonder they appear as incredibly small dots. Most stars are much further away.

I used a golf-ball analogy for Mars' distance earlier. A golf-ball is about 43 mm in diameter. 100 million times this diameter is 4300 km distance. At this distance a golf-ball would indeed appear as an incredibly small dot or in reality would not appear at all. Even with a magnification of ×1000 (which is more than the atmosphere in most places allows you to get) a golf ball sized object at 4.3 km still appears as a very small dot, if you could see it. The furthest stars (or galaxies of stars in fact) seen by the professionals are over 1 billion times the distance of the nearby stars. In short, stars are spread very thinly over absolutely vast distances.

For looking at stars, even nearby stars, magnification is not the main purpose of a telescope. The purpose is light grasp – collecting more light. More light makes fainter stars visible and fainter features of nebulae visible. By and large, the leading telescopes of professionals have increased in diameter over the past century as far as technology has allowed. About 10 m is the currently affordable limit, though plans are afoot for two or three outstandingly large telescopes, larger than any one country can afford. For an amateur starting out, a telescope up to 0.2 m diameter makes sense and a decent one can be bought for a 3-figure sum (in £). If you're very keen on deep space objects then a bigger 'Dobsonian' can still be purchased for a 3 figure sum. More on this later.

Magnification isn't useless. It does actually have two rôles to play. Too little magnification and stars that should appear separated merge together. For example, binary stars may be seen as singletons, globular clusters will be unimpressive. Too much magnification and you won't see details of nebulae you're looking at or faint light will be too spread-out in the image. Secondly, planets, their moons, our moon, comets and objects that really do have a shape one can see will of course potentially benefit from magnification. One price to pay for magnification is that the images of all objects dance around in the field of view because of atmospheric fluctuations and this dancing is also magnified. There comes a time when you see less with more magnification. To make matters worse, with high magnification tracking a moving star or planetary image (because we are on a spinning Earth) becomes harder and, in addition, image quality is generally not so good. The '*seeing*' varies a lot with weather but in my experience, here near sea level magnifications greater than x100 need good seeing conditions to be useful. A second price to pay for magnification is that with a given objective an eyepiece that gives greater magnification spreads out the same light more and the image becomes dimmer. Larger magnifications are therefore better with wider telescopes.

What kind of telescope?

Anyone who owns a car will get more out of it and be more sensitive to any fall-off in performance if they have some idea what's under the bonnet. Likewise a telescope owner will get more out of it if they have some knowledge of the optics and mechanics of the device. There aren't many adjustments one regularly needs to make to drive a telescope; just rotational orientation and focusing. However, this supposes that the pieces that are supposed to be fixed and aligned remain that way. What are these pieces?

Astronomical telescopes for eyeball observation have two main optical components: the objective and the eyepiece. The eyepiece is always a combination of lenses, usually between 2 and 6, though zoom eyepieces may have more. The lenses have an axis of rotational symmetry so it doesn't matter how the eyepiece is rotated in its holder. The eyepiece designer tries to ensure minimum chromatic aberration and that stars at the edge of the field of view are almost as well focused as central stars. Generally the wider the field of view, the more expensive is the eyepiece. Eyepieces come in standard physical widths and can be used in more than one telescope but are likely to give the best images in the manufacture's telescope they were designed for. In passing I'll add that the magnification of a telescope is given by the ratio (objective focal length)/(eyepiece focal length). Eyepieces that magnify more have a shorter focal length and are in general are harder to design and manufacture so that they maintain a good image over a wide field of view.

In a *refracting telescope*, the objective is also a lens, placed at the front end of the telescope tube. This lens also has rotational symmetry and the housing of the telescope should ensure that this axis is accurately aligned with the eyepiece axis. If it isn't then image quality will suffer but unless you have taken the telescope apart and mis-assembled it, alignment isn't likely to be an issue with a refracting telescope. In a refracting telescope you look straight through. This isn't always the case for a *reflecting telescope*. Reflecting telescopes include two mirrors, a large objective mirror and a smaller secondary mirror. This isn't the place for an optics lesson but, briefly, the large mirror is located at the back end of the telescope tube. In the optically simpler *Newtonian* system, the secondary mirror is a flat mounted at 45º near the front of the telescope and you as observer look in at right angles through the eyepiece near the front. In the *Cassegrain* system, the secondary mirror is a convex mirror mounted centrally in the tube that reflects the primary image back through a hole in the mirror into the eyepiece that is located on the axis behind the mirror. The popular *Schmidt-Cassegrain* has an additional full-width thin lens near the front of the tube that creates a much wider field of view than can be obtained with an objective mirror alone.

Every telescope needs a small finder or sighting telescope attached to its barrel. When you look through the main telescope you will see a field of stars, most of which aren't visible to your naked eye. Without a lot of experience it won't be at all obvious exactly where you are looking. The finder telescope is a low power monocular with cross-wires that should be placed at the centre of where the main telescope is pointing. The Newtonian arrangement is less convenient because the finder telescope lies along the barrel but the eyepiece is at right angles. In recent times some people have taken to using a laser pointer as a finder but that has its hazards.

In all the kinds of telescopes just described, the eyepiece is placed beyond the place where the objective focuses the light. Effectively the eyepiece is a small microscope that examines the objective image. Optically, the telescope must be longer than the focal length of the objective. Now width, focal length and image quality of a lens or mirror are related so that the focal length of the objective shouldn't be much less than 8 times its width for a good image. Hence wider telescopes of a given kind will also be longer and larger telescopes.

Why all the different types of telescopes? Each is some form of compromise to an ideal instrument. The refracting telescope is optically and mechanically the simplest, with fewer things to go wrong. However, from what's just been said, the wider its objective is made the longer the telescope must become. Since the objective lens must be polished on all its faces (it is normally a composite of at least two pieces of glass) and made from the very highest quality optical glasses, even medium sized objective lenses are heavy and expensive. The net result is that refracting telescopes for the amateur are generally small. Mirrors, on the other hand, need only be polished on one face, can be thinner than the corresponding lens and even made of opaque material and hence are lighter and cheaper than a lens of the same diameter. They don't have to be mounted around the rim only. In the Cassegrain system the light-path is folded and hence the telescope is less than half the length of the corresponding refracting telescope, and lighter. In short, you usually get more for your money with a reflecting telescope but they are more complex and have more components in them that may be knocked out of alignment. You won't have to go far to find an amateur who will recommend a 100 mm refractor as an excellent, simple starting telescope. You could buy one of these off-the-shelf two hundred years ago (maybe not as good as a modern one) so I'm persuaded that a 200 mm Schmidt-Cassegrain or similar reflector of comparatively modern design using modern materials is the starting telescope of choice today. Some of my reasons are given below.

Putting it all together

It took an amateur to show the professionals the way forward for astronomical telescopes more than two centuries ago. That amateur was the musician William Herschel, who himself became a consummate astronomical professional patronised by King George III, though he was never appointed Astronomer Royal. He might have had the motto 'more light' for he showed that width was more useful than length in an astronomical telescope. Width brings in more light, giving brighter images, showing more faint stars and fainter objects in the solar system, better detail of deep sky objects. Width scores on almost all counts so that's why my preference is to go for a reflecting telescope of the widest diameter that other considerations allow. What are the 'other considerations'? Some are:

- *cost*. You need to be sure to include a suitable tripod or support. Telescopes are much heavier than cameras and generally require counterbalancing so get a telescope tripod, not a camera tripod no-matter how sturdy it looks. The alternative is a fixed cradle in your own shed with sliding roof or observatory.
- *manoeuvrability*. Is the telescope going to sit on a permanent mount or is it normally going to be carried out into the garden or transported in the boot of a car to a better dark site along with its tripod?
- *ease of use*. Is the telescope easy to set up and look through?
- *GOTO facilities*? Many modern telescopes can be plugged into a portable PC and a variety of software, some freely downloadable, can be used to point a telescope that has been initially aligned in the sky, either selected from a menu or from the cursor position on a screen showing a map of the sky. It is a marvellous development but adds weight, complexity and cost. Some telescopes have their own controller and don't need the attached PC. Of course a 'GOTO' facility requires electrical drive and that means an accompanying battery of suitable oomph if you have a portable system.
- *alignment option*. The cheapest telescopes leave the method of alignment up to the user or provide nothing more than some kind of universal joint. You'll quickly get fed up with this. It's impractical. The two basic alignment strategies are '*altitude/azimuth*' (alt/az) or *equatorial mount*. In alt/az one motion controls the tilt of the telescope in a vertical plane and the other the motion around the horizon in a horizontal plane (if the tripod is correctly levelled!). Since the natural motion of the stars across the sky is a rotation around an axis aligned with the poles, then to follow a star requires the simultaneous application of both motions at exactly the right speed. One might have thought that a computer-controlled telescope would cope with this but star images are so small that the accuracy required for excellent tracking is very high and in my limited experience this is the less satisfactory option.

  The alternative is the '*equatorial mount*' in which the main rotation axis of the telescope is aligned with the celestial pole. This enables the motion of any stellar object to be followed by only a single rotation. The equatorial mount has another advantage in that it needs less in the way of preliminary adjustment. The axis just needs to be set up on level ground along the north-south line.
- *attachment options*. Does my chosen manufacturer produce a range of attachments that will allow me, perhaps at a later date, to attach a CCD camera, filters and other accessories? This may not be relevant for a first telescope but once bitten by the bug you may well want to try to produce pictures of the quality that other amateurs manage.

I mentioned 'Dobsonians' above. The Dobsonian is the telescope in which the biggest fraction of your money goes on a large mirror. The basic design is Newtonian with a parabolic mirror. The mirror sits at the bottom of a tube mounted in a cradle. The cradle sits on a swivelling base that you place on the ground. The mounting is about as simple as one can imagine and lighter to carry around than others for the same width of telescope. A parabolic mirror gives good images only over a small field of view so the big mirror and small field make the Dobsonian the best your money will buy for looking at deep sky objects, and planets if it comes to that. If you want to look and not take pictures, and haven't a permanent shed or observatory, there is a lot to be said for the Dobsonian.

Solar telescopes

Observing the Sun is gradually becoming more and more popular. The Sun is the most important star in the sky. You can observe it at civilised hours of the day without wrapping up in thermals and a fleece or worrying about street lights and the dome of city light pollution. Indeed, it's an activity for a fine day. The combination of changing solar spots, prominences and the Sun's rotation mean that the Sun doesn't look the same on two successive days.

The Sun is about 8 light minutes away and a nearby star may be 8 light years distant, just over half a million times as far. A normal telescope is happy pointing at a sun-like star 8 light years away but bring that star half a million times closer and the amount of light received increases by around 0.5×10^6 squared, namely 2.5×10^{11} times. That's coming up to a million, million times. Don't point your stellar telescope at the Sun, even when you're nowhere near the eyepiece.

There are ways of using a normal small telescope to view the Sun but to make solar observing a hobby then think of getting a solar telescope. These come with an in-built safety design and one or more narrow-band filters that allow you to see the emission from specific elements. Hydrogen-alpha is the obvious one, highlighting emission from the chromosphere; Ca-K another one, near the violet end of the spectrum. White light viewing is also available. Attaching a digital camera to record the solar appearance is well worth it but how easy this is will depend on your telescope and camera. Exposures are brief but as with the stars fine detail is lost because of atmospheric turbulence and to recover it 'stacking' software that combines the images of repeated exposures will substantially improve your results.

I've seen many excellent images from a Coronado PST (personal solar telescope). Lunt are a competitor manufacturer and there are more expensive suppliers too. Solar telescopes are more costly than stellar telescopes of the same aperture because the solar filters within them (Fabry-Perot etalons for the initiated) are more expensive than lenses or mirrors. There are countries in the world where you can get bored with seeing the Sun every day almost all day but in Scotland the appearance of a nice sunny day will get you setting up your solar scope to see how the sunspots, faculae and prominences on our nearest star have developed.

Conclusion

The above is more than enough to be thinking about. Astronomy is a popular hobby. There are lots of astronomical societies around the country and Aberdeen is no exception in having one. If you come along to a local meeting of the Aberdeen Astronomical Society, introduce yourself and ask around about buying a telescope. You will quickly find members with a wide range of experiences. Keen amateurs often end up going up-market and may have perfectly good equipment for sale. The less keen may have equipment for sale that has been little used, so either way buying second-hand may be a good entry strategy. I hope this introduction will be of some help if you are just starting out on this hobby. It's a hobby that may last you a lifetime.

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