Darkness, Light, And How Symmetry Might Relate Them

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Abstract

Alan Barr explores light and darkness in the context of physics. In particular, he discusses light, the theory of electromagnetism and the electromagnetic spectrum. Barr explains what neutrinos are and the difficulty of studying them due to their lack of interaction with light. The chapter also discusses dark matter, and its possible more profound links with light via supersymmetry.

There is much more to darkness than just the absence of light.

The first kind of darkness is the absence of light. Blank out the sun, the moon and the stars, remove candles, torches and artificial lights, and the world goes black. No beams of light spread out to illuminate our world. No scattered rays bounce off our surroundings and pierce our eyes. No photons excite the cells in our retinas, tingle the nerves that run to our brain and paint a picture of the world around us.

But that is not the only kind of darkness. To understand the other kinds we first need to understand light.

To a physicist, rays of light carry energy and information in physical form. Light rays are interconnected ripples, speeding undulations of electricity and magnetism. They need no medium though which to pass, and so travel unimpeded through the vacuum of space. Unbounded in their range, and travelling at the ultimate top speed, they convey to us messages about objects at immense distances and times long past.

The information in light is mostly carried in the spectrum of colours it contains. The different colours in the rainbow are rather like the different musical notes. Red light is the deeper, lower-frequency notes. It comes from longer, slower molecular or atomic oscillations. Blue and violet are like the high notes, and are created from short quick oscillations. Green light lies between, in the middle of the visible spectrum. These colours when combined together make white light, a full electromagnetic cacophony of optical noise.

Beyond the colours of the rainbow, which span a single “octave” of the optical spectrum, there are at least eighty more octaves stretching both to lower and higher pitches. These are the warm infrared rays that let us feel the heat of the sun, and the longer microwaves that might warm our supper. With the right instruments we can detect light from the lowest notes of radio waves right up to the highest pitched x-rays and gamma rays from nuclear decays.

Even within the single octave of the visible light, there’s plenty of variety. The various colours behave differently as they ripple through and interact with the material world. As the sun rises, the first rays glancing the earth’s surface must pass far through the atmosphere to reach our eyes. Dust and gas scatter the blue light away leaving only a red sunrise glow to reach our eyes. Later in the day, with the sun high in the sky, it is that same blue scattered light, seen from a different perspective, that gives sky its blueness.

Materials too respond differently to different parts of the spectrum. Pigments appear purple or yellow or orange, precisely because they absorb only certain colours and transmit others. Grass looks green because chlorophyll in its leaves absorbs red and blue light, leaving only the green to be seen. But a black cloak is black because it indiscriminately absorbs all visible light, leaving none to scatter to the eye.

This is the second kind of darkness – the darkness of soot, of the crow’s wing, or the blackberry. This darkness is caused by objects interacting with and responding to light. Dark objects are dark because they absorb almost all the light that falls on them. The molecules within them feel the pulsating electric field, absorb its energy and jump to excited configurations. When they later give out that energy, they do so in parts of the spectrum that we can’t see. The light that hits them never gets observed. They look black, almost as if no light had struck them. But it’s an imperfect darkness. The reemitted light, though invisible to the eye, is merely shunted beyond the visible spectrum. A crow seen by an infrared camera will still appear to glow brightly. It turns out to be most useful to us that each atom or molecule has its own characteristic set of optical harmonics. We can find out what the particular notes of light are that different materials emit and absorb. Those patterns are unique to each species. Armed with a catalogue of optical harmonics we can work out the properties of distant materials - even those far out in space. The sun and the stars, for example, produce light stamped with the patterns of the simplest two elements, hydrogen and helium. Even though we aren't able to gather a scoop of the super heated plasma from the surface of the sun, we can tell what it is made of by the light it sends us. Understanding its substance in turn helps explain how stars like the sun can burn for so long. The pressure in the centre of the sun squeezes and transmutes hydrogen into helium, releasing vast amounts energy in the process. That energy is eventually released from its surface as the sunlight we observe.

But stars emit more than just light. A few percent of the energy they produce is instead radiated away as ghostly particles known as neutrinos. These subatomic waifs are created in the same fusion reactions that produce light in the core of the sun. But unlike light, which bounces and scatters around inside the sun, the neutrinos barely interact at all. Unresponsive to either electric or magnetic fields they travel almost unimpeded through the sun, the earth, and indeed any observer that attempts to try to catch them. Billions of these neutrinos pass through our bodies every second, unobserved, undetected, and undeflected.

These neutrinos exhibit the third kind of darkness. They are dark not because there is no light to strike them, like the darkness of the night. Nor are they dark because they absorb all the light that falls on them, like soot. Neutrinos are dark because they are transparent. They can't be lit up because light will not bounce off them. This total transparency is not a property of any familiar objects. Any solid, dust, gas, or plasma will absorb some part of the wide range of the electromagnetic spectrum. Glass looks transparent to visible light, but it nevertheless absorbs infrared and ultraviolet light.

Neutrinos, unlike glass, are transparent to the whole spectrum of electromagnetic radiation. Neutrino means little neutral ones. Being perfectly neutral they just don't feel the oscillating electromagnetic waves of light at all. Light of all colours passes clean through them. Shine a light out into a sea of neutrinos and what you will see is pure unresponsive darkness. This kind of darkness, the darkness of the neutrino, makes them exotically invisible. And a substance that is unseen and non-interacting is hard to study. It provides us with no characteristic spectral harmonics to probe its inner working. No scattered light tells us about its structure and form. We see only darkness and so are both literally and metaphorically unenlightened about its nature.

With the neutrinos we have managed, eventually, to find other ways understand them. These are techniques that don't rely on interactions with light. Over the last few decades, we have made precise measurements of their feeble interactions and started to tease out some of their secrets. One of the things we have found is that they have extremely tiny masses. Neutrinos are the opposite of heavy, but let's not say they are 'light', lest we further confuse the issue.

Studies of the structure evolution and evolution of the universe have led us to understand that there must be some other substance that doesn't interact with light. This material is called dark matter. It is dark in the same sense as the neutrino, in that it simply seems not to interact with light. It is mysterious for the same reason too – things which do not interact are hard to understand. Ironically we only found out about the need for dark matter through the study of light - starlight. Stars that are moving away from us have their light stretched, lowering its optical pitch. Those stars zooming towards us have compressed light waves, producing higher notes. The characteristic optical signatures imprinted in the light by the stars also get squeezed and stretched, and so encode the star's speed in the harmonics of the spectra we observe.

The stretched and squeezed light that reaches us from these speeding stars tells how fast they are rotating around their host galaxies. They ought to be following predictable orbits rather like those of the planets orbiting the sun. The speed of their trajectories depends on the amount of mass that's drawing them in towards the centre of their galaxy. But the inferred speeds are far too high to be explained by the gravitational pull of the other stars alone. Even when stray dust and gas is added to the equation the peripheral stars are travelling at speeds that should shoot them out into space.

The simplest explanation is that some extra mass is drawing them in. The additional matter does not emit light, and so became known as *dark matter*. It's not dark in the sense of the absence of light, since it is surrounded by luminous stars. Nor is it the darkness of soot, since it neither absorbs nor emits light in any part of the spectrum. Its darkness is non-interacting transparent darkness, like that of the neutrinos. But unlike the neutrinos, dark matter has enough mass and gravitational tug to hold galaxies together.

Other observations have shown that dark matter also pulls on large clusters of galaxies, directing their formation and evolution. Dark matter was present before the galaxies were born. And right in the early universe, before the first stars, before even the first atoms condensed out of the hot plasma of the big bang, dark matter was there, tugging on the proto-atoms. All these observational clues point in the same direction. Dark matter is a heavy invisible material, quite unlike anything we have detected so far on earth.

This material is dark in the physical sense that it has no interactions with light, but also dark in a metaphorical sense. We know very little about what it's made of. Indeed, about the only thing that we really know (other than its transparency which makes it dark) is roughly how much of it there is. The total amount, when added up across the universe, is rather a lot. In fact there seems to be several times more mass of dark matter in the universe than all of the matter contained in all the stars, dust and gas combined.

Our state of almost complete ignorance about dark matter doesn't stop imaginative and creative people from dreaming about what it might be made of. It's a fruitful field of study and speculation. It turns out that there are very many different ways in which one can explain theoretically something about which there is so little empirical knowledge.

Amongst these many theories of dark matter some of the most striking relate it by symmetry to other particles that we already understand very well. Indeed in some of the most interesting theories the dark matter is not so different from light itself. These latter theories involve various types of mathematical or geometrical symmetry that directly relate the dark matter to light. It might seem odd that dark matter, which is by definition dark, might be closely related to light. But, counter-intuitively, light does share some of the properties expected of dark matter. Rays of light pass straight through one another, without interacting, colliding or reflecting from one another. The little packets of energy that make up light, known as photons, shoot straight through one another. Light is transparent to light. And in this sense it shares the property of transparent darkness that we previously encountered in the neutrino.

One class of these speculative theories suggests that dark matter is a form of excited photon with its energy stretched out into other invisible dimensions of space. This excited light would gain mass, travel slowly and look very much like dark matter. A second class of theory says that dark matter is made of a partner of light called the photino. In this scenario the dark cousin of light is made heavy through the breaking of a symmetry that relates matter to force. The photino would also share light's natural property of transparency. Unlike light it would be heavy and sluggish due to an imperfection in the symmetry. This second type of theory is called Supersymmetry and it too could be the perfect explanation for the dark matter.

For the moment these theories are only speculation. Dark matter and light might indeed be related by a deep symmetry - but we won't know until we can study the dark matter, and its relationship with light, more closely.

Efforts are currently under way at Large Hadron Collider near Geneva in Switzerland to produce and record the presence of man-made dark matter. Other experiments are seeking it in mines deep underground. The scientists and engineers working on these are attempting to detect the rare collisions between atoms and the relic particles of dark matter left over from the big bang. Other experiments again are looking out into space, searching for the light that might be emitted on the very rare occasions that pairs of dark matter particles collide, are annihilated, and yield up their energy in visible form.

None of these terrestrial experiments has yet been able to observe and identify the dark matter that we know – from the gravitational pull of its mass – must exist. But on they search, in hope and expectation.

Perhaps soon we will start to understand the nature of the dark matter. With patience we might get to know it well – even as well as we do the once-mysterious pinpricks of light in the night sky that are the stars. Our minds, not constrained to understanding only those things that can be seen, could then gain insight into both the light and the dark matter in the universe.[1]

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[1] Reproduced from *The Language of Symmetry* (Eds. Rattigan, Noble & Hatta), 2023