SHADOWLANDS

Quest for Mirror Matter in the Universe

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Shadowlands: Quest for Mirror Matter in the Universe

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The picture on the cover shows the crab nebula–the remnants of a star which exploded in 1054.This photograph was taken at the European Southern Observatory. (Credit: FORS Team, 8.2-metre VLT ESO).

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Preface

My purpose in writing this book is two-fold. First, many non-specialists ask me to explain the mirror matter idea and the scientific evidence for it. Second, science is so specialized these days that many people who know a lot about one field often know little about another. Mirror matter, if it exists, would lead to rather important implications for several scientific fields, including: particle physics, astrophysics, cosmology, meteoritics and planetary science. Thus, it seemed to me that an interesting challenge would be to write a book explaining the motivation for mirror matter and its evidence which could usefully serve these two communities (that is, both specialists and non-specialists alike). Such a venture, though, is not without risks of various kinds. Let me state at the outset that the mirror matter idea is not established fact; it is an example of cutting-edge science in progress. It is my hope that people who read this book will be infected by, or at least understand, my enthusiasm for this subject, and why I think it is one of the most interesting questions in science at the moment.

The process of writing this book gave me the opportunity to rethink many of the original arguments. Some 'gaps' in my knowledge were filled in, and a few new directions explored. Some material is therefore completely new, although most of it has appeared in the technical scientific literature previously. I have only cited this scientific literature sparingly, but nevertheless I have endeavoured to properly credit the people responsible for the main original ideas.

It seems only yesterday that I learned as a student that mirror reflection symmetry was not respected by the fundamental interactions of nature. Electrons and other elementary particles are, in a sense, 'left-handed'. Although most scientists have simply come to accept that God is 'left-handed', somehow it always bothered me....

One sunny afternoon in May 1991 a rather remarkable thought occurred to me. While playing with an unrelated idea, it suddenly struck me that there was a subtle yet simple way in which mirror reflection symmetry could still exist. Nature's mirror could be unbroken if each type of ordinary particle has a shadowy mirror partner. The left-handedness of the ordinary particles could then be balanced by the right-handedness of the mirror particles. So there you have it, mirror reflection symmetry can exist but requires something profoundly new. It requires the existence of a completely new form of matter called 'mirror matter'.

At first, it seemed too fantastic to really exist. Yet, over the last few years it appears that almost *every* astrophysical and experimental prediction of the mirror matter theory has actually been observed by observations and experiments: There is fascinating evidence for mirror matter in the Universe from astronomical observations suggesting that most of our galaxy is composed of exotic dark material called 'dark matter'. Recent particle physics experiments have revealed unexpected properties of ghostly particles called 'neutrinos' and weird matter anti-matter atoms. This unexpected behaviour is expected if mirror matter exists. Most remarkable of all is the evidence that our planet is frequently bombarded by mirror matter asteroid or comet sized objects, causing puzzling events such as the huge 1908 Siberian explosion which felled more than two thousand square kilometres of native forests without leaving a single meteorite fragment behind! Altogether I will discuss seven major puzzles in astrophysics and particle physics each arguing in favour of the mirror matter hypothesis. There are indeed seven wonders of the mirror world...

New data from current and future experiments will keep coming in even as this book is being printed. Unfortunately, I am not a fortune teller and do not know what these future experiments and observations will find. However, I can predict what they will find if mirror reflection symmetry and hence mirror matter exists. The case for mirror matter will therefore either strengthen or weaken as new data comes in and future experiments are done. In the meantime, I advise you to sit back, relax and let me take you on a journey exploring one of the boldest scientific ideas ever proposed.

No scientist works in isolation and I am no exception. I have had fruitful collaborations on mirror matter with a number of very creative people, including Sergei Gninenko, Sasha Ignatiev, Henry Lew, Zurab Silagadze, Ray Volkas and T. L. Yoon. I have enjoyed interesting correspondence on some aspects of this subject with Sergei Blinnikov, Zdenek Ceplecha and Andrei Ol'khovatov. In addition, I would like to acknowledge invaluable support over the years from many friends and colleagues including in particular, Pasquale Di Bari, John Eastman, Greg Filewood, Dave Howland, Girish Joshi, Matthew Tully, and Nick Whitelegg. I am also greatful to many of the above people, and also Jaci Anderson and Glen Deen for providing me with useful comments on the manuscript and Tony Nguyen for helping with the cover.

Of course, I thank my family most of all. It is to them that I dedicate this book.

Robert Foot
August 2001

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for Carolyn and James

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Contents

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There are more things in
Heaven and Earth, Horatio, than
are dreamt of in your philosophy.

William Shakespeare – Hamlet.

PART I

Why Mirror Matter?

Chapter 1

Introduction

Shortly before his death in 1727, Isaac Newton reflected upon his life and wrote[1]:

> I don't know what I may appear to the world, but, as to myself I seem to have been only like a boy playing on the sea shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

More recently in Stephen Hawking's *a brief history of time*, it is written[2]:

> I still believe that there are grounds for cautious optimism that we may now be near the end of the search for the ultimate laws of nature.

The contrast between the current Lucasian Professor and the former holder of that position is striking. Hawking is not alone in his prophecy. It has been repeated with monotonous regularity since the days of Maxwell (1865). One day it may come true, but that day is a long way off. I believe that a revolution in science may be imminent. In fact, over the last decade, remarkable evidence from astronomy (studies of the very big) to studies of the elementary particles (the very small) suggest that a completely new type of matter exists – 'mirror matter'. The best ideas in science are usually very simple, and fortunately mirror matter belongs to this category. I believe that the ideas and the evidence can be appreciated by anyone interested in science.

In the process of uncovering mirror matter we will encounter many recent and unexpected discoveries, including:

- Invisible stars which reveal their presence by gravitationally bending the light from more distant stars behind them. I will argue that these invisible stars are made of mirror matter which can simply explain why we don't see them.

- Planets orbiting nearby stars which are *eight times* closer to their star than the distance Mercury orbits the Sun. I will suggest that these unexpected planets are expected if they are made of mirror matter.

- Bizarre, apparently free-floating planets wandering through space. They can be more naturally interpreted as ordinary planets orbiting mirror stars, but I could be wrong!

- Strange and unexpected properties of elementary particles such as the ghostly neutrinos. These particles are emitted from the Sun and in other processes. However, half of them are missing! The missing neutrinos may have been transformed into mirror neutrinos as I will explain.

- I will also discuss a strange class of 'meteorite events' such as the huge Siberian 1908 explosion and other similar such explosions. There is evidence that these explosions are caused by the random collisions of our planet with orbiting 'mirror matter space-bodies'. Most remarkable of all is the real possibility that mirror matter remnants may still be in the ground today! Needless to say the possible uses of this new type of matter are not even imagined...

By the way, this is a (generally) serious scientific book. However, unlike other 'serious scientific books' this book does not claim to reveal the 'mind of God'. In fact, not many ridiculously grandiose statements will be made at all. Rather, it is simply a book about mirror reflection symmetry – and its far reaching implications.

Symmetry is a word frequently used in everyday language and we are all aware of what it means. Examples of symmetrical objects abound: flowers, butterflies, snowflakes, soccer balls and so on... In fact, as some of these examples illustrate, symmetry is often associated with beauty and vice versa. It is perhaps not surprising then that symmetry plays a pivotal role in our understanding of the elementary particles and their forces, but let me start at the beginning.

There are many distinct types of symmetry. The symmetry of a mushroom is completely different to the symmetry of a butterfly which in turn is completely different to the symmetry of a soccer ball. A butterfly is an example of the most familiar symmetry – 'left-right' symmetry. This symmetry occurs when two equal portions of a whole are the mirror image of each other. For obvious reasons, this symmetry is also called 'mirror' symmetry. A soccer ball is an example of another type of symmetry – rotational symmetry. In fact, it is an example of an object with three dimensional rotational symmetry because rotations around any axis do not change the appearance of the ball. Finally a straight fence or railway line are examples of objects which display another type of symmetry – translational symmetry. A railway line or fence looks the same as we move along it.

Fortunately the everyday usage of the concept of symmetry is exactly the same as its technical usage in science. Although it is often useful to describe symmetry in a mathematical way – this need not concern us. Here we need only discuss the ideas and concepts which is enough to glimpse the beautiful world of the elementary particles and their interactions.

Most people are aware that ordinary matter: you, me and everything else we see, except light itself, is composed of atoms. Although atoms are very tiny, approximately one ten millionth of a millimetre in size, they are still not the most fundamental building blocks of matter. Atoms are not *elementary* entities. Each individual Atom is made up of electrons and a compact nucleus, which in turn is made from protons and neutrons. There are about 100 different types of atoms depending on the number of electrons that they contain. The science of atoms, how they interact with each other to form molecules and how different molecules interact with each other is of course the science of chemistry. However, we will not be involved so much with chemistry but with the most fundamental of the sciences – physics. One thing that physics is concerned with is the most basic questions that can be asked. For example, what are the properties of the elementary particles: protons, neutrons, electrons from which all matter is made? How do these particles interact with each other and with light?

One thing that has been learned over the years is that the interactions of elementary particles display a variety of symmetries. Some of these symmetries are quite familiar such as rotational symmetry and translational symmetry. Thus, the laws of physics remain the same whether we are in Melbourne or in Moscow, which means that Russian physics text books are useful in Australia and vice versa (after they are translated...). In addition to translations in space (and translations in language!) we can imagine translations in time. The laws of physics are the same today as yesterday or even a century ago, however our knowledge of these laws generally improves as time goes by. Hence, physics text books are not the same today as a century ago, yet the laws of physics are the same. There are still other more abstract symmetries of the elementary particle interactions. These are called 'Lorentz symmetry' and 'gauge symmetry', which are nevertheless quite elegant and natural once you get to know them.

Progress in science is rarely a smooth comfortable journey. Rapid progress generally occurs in brief intervals usually through new and unexpected experimental results and sometimes through novel theoretical ideas. Of course progress is most rapid when theory and experiment move together in harmony. One of the most remarkable theoretical ideas of the 20^{th} century was the discovery of relativity theory in 1905 by Albert Einstein. Space and time were unified with time becoming the fourth dimension. Einstein suggested that the laws of physics were symmetrical under rotations in this four dimensional space-time, rather than just the three dimensions of space. The predictions of this theory, such as moving clocks must run more slowly, have been experimentally verified with tremendous precision. This is possible because Einstein's theory not only tells us that moving clocks run more slowly, but it tells us exactly how much more slowly! This four dimensional rotational symmetry of space-time is called ‘Lorentz symmetry’*.

There are four known fundamental forces in nature: gravity, electromagnetism, weak and strong nuclear forces. Gravity is quite familiar to most of us. It keeps our feet on the ground, it keeps our planet and all the other planets in our solar system in orbit around the Sun and it keeps the Sun in orbit around the centre of our galaxy. Electromagnetism is no less important – while it is gravity that holds us down, it is electromagnetism that stops us from falling through the floor. It is also the force responsible for electricity and magnetism. While the weak and strong nuclear forces are less familiar, they are nevertheless equally fundamental and important as the other more familiar forces. For example, the weak and strong nuclear force provides the energy which powers the Sun, without which our planet would be too cold to sustain life.

Today we know that three of these forces, electromagnetism, the weak and strong nuclear forces are, mathematically, very similar and fairly well understood. Gravity, on the other hand, is quite different and its relation to the other forces is somewhat mysterious. One reason is that gravity can be described in geometrical terms as a curvature of four dimensional space-time while the other three forces are described in terms of symmetries on an abstract ‘internal’ space, which is nothing to do with ordinary space-time that we know about. These peculiar symmetries of the electromagnetic, weak and strong nuclear forces are called ‘gauge symmetries’.

Evidently, symmetries are rather important in understanding the elementary particles and their forces. However, it is pertinent to recall that these symmetries were not always so obvious. I have already mentioned the case of Lorentz symmetry – the rather abstract idea that space and time can be treated mathematically as a four dimensional space-time. In fact, after the discovery of relativity theory and Lorentz symmetry, an English Physicist called Paul Dirac uncovered a big problem. In the late 1920’s Dirac noticed that a microscopic mathematical description of the electron consistent with

*In addition to Albert Einstein’s insight, important contributions to the relativity theory were made by others, including: Hendrik Lorentz, Hermann Minkowski and Henri Poincare.

Lorentz symmetry was not possible, unless something completely new existed. Nothing short of a new form of matter was required to reconcile Einstein's relativity theory with the quantum mechanical theory of the electron. This new form of matter, called 'anti-matter' was thereby theoretically predicted to exist.

Specifically, Dirac predicted that in addition to the particles that make up ordinary matter – the electrons, protons and neutrons, anti-particles called 'positrons' (or anti-electrons), 'anti-protons' and 'anti-neutrons' should all exist. The symmetry required each type of anti-particle to have the same mass as the corresponding particle. Positrons and anti-nuclei (made from anti-protons and anti-neutrons) should form 'anti-atoms'. However, anti-particles should annihilate when they meet ordinary particles producing gamma rays (high frequency light). History tells us that experiments shortly followed which dramatically confirmed the existence of Dirac's anti-particles. First, the discovery of the positron in 1932, and later, the discovery of anti-protons in the 1950's. Anti-matter is not science fantasy but science reality. Clearly, the idea of symmetry can have remarkable implications.

This book though, is concerned not with Lorentz symmetry but with left-right or mirror reflection symmetry. Let us now briefly look at the history of this symmetry. Before 1956 physicists had assumed that the laws of physics were symmetric under left-right symmetry. This would mean that for every fundamental microscopic process that is known to occur, the mirror image process should also occur. In fact left-right symmetry is such a familiar and plausible symmetry of nature that it was never seriously questioned until various experimental puzzles began appearing in the 1950's. These puzzles led T. D. Lee and C. N. Yang to suggest that the weak nuclear force does not display left-right symmetry. They proposed an experiment to directly test the idea involving the β-decay of an unstable isotope...

At the time, most scientists didn't expect that mirror symmetry could really be broken. The prevailing scepticism was summed up by Wolfgang Pauli when he wrote in December 1956[3]:

> I am however prepared to bet that the experiment will be decided in favour of mirror invariance. For in spite of Yang and Lee, I don't believe that God is a weak left-hander.

However, Pauli was not so foolish as to let his beliefs get in the way of science. He did agree that experiments should be done to check it[4]:

> I believe in reflection invariance in contrast to Yang and Lee... Between believing and knowing is a difference and in the last end such questions must be decided experimentally.

The experiment suggested by Lee and Yang was performed in 1957 by C. S. Wu and collaborators. In this experiment a number of cobalt-60 atoms were cooled down to near absolute zero Kelvin (the lowest possible temperature) and placed in a strong magnetic field. Cobalt-60 is an unstable isotope. Ordinarily, Cobalt-60 decays emitting an electron with any direction equally likely. However, under these extreme conditions, the electrons should be equally likely to emerge from the two poles of the magnetic field – if the fundamental decay process displayed mirror symmetry. Yet, it was observed that more electrons came out from one direction than the other. If we observed only one nuclei decaying we could not say anything. Mirror symmetry does *not* mean that each single interaction or decay process is the same as its mirror image – it is not. Mirror symmetry means that the mirror image process can occur and should occur with equal probability. Therefore, by observing a large number of decays of Cobalt-60 we can easily determine whether mirror symmetry is violated. The remarkable conclusion was that the fundamental laws of physics appear to be 'left-handed'. This is really very strange. Every other plausible symmetry, such as rotational and translational symmetry, are found to be microscopic symmetries of particle interactions. Can nature really be left-handed?

Are they, the fundamental laws of physics that is, really left-handed or do they only appear to be left-handed? Remember our earlier comments about Lorentz symmetry. At one time this symmetry did not *appear* to be a symmetry at all. This was because anti-matter had yet to be discovered. Only when you have particles and anti-particles is it possible to write down a consistent microscopic theory for the interactions of the electron, proton and neutron which respects Lorentz symmetry. Remarkably, it turns out that it is still possible for particle interactions to be symmetric under mirror or left-right symmetry. Just as Lorentz symmetry required the existence of anti-matter, left-right symmetry can exist if and only if a new form of matter exists – mirror matter.

Often, it seems that nature is more subtle and beautiful then first imagined. It could be that nature's mirror is of a more abstract kind. Imagine that for each type of ordinary particle there is a separate 'mirror particle'. That is, not only do we have photons, electrons, positrons, protons etc., but also mirror photons, mirror electrons, mirror positrons, mirror protons etc. We can imagine that in nature's mirror not only space is reflected but also particles are reflected into these mirror particles. The relationship between ordinary and mirror matter is somewhat like the relationship between the letters 'b' and 'd'. The mirror image of 'b' is the letter 'd' and the mirror image of 'd' is the letter 'b'. Thus, while neither 'b' nor 'd' is symmetric (in a sense they each have the opposite handedness), together 'bd' is in fact mirror symmetric, with the two letters interchanging in the mirror image[5]. Try it with a mirror and see! Still, the mirror reflection of an object appears very similar to the original. It is perhaps not surprising, therefore, that the properties of the mirror particles turn out to be very similar to the ordinary particles. For example, the mirror particles *must* have the same mass and lifetime as each of the ordinary particles, otherwise the mirror symmetry would be broken.

In some ways mirror particles resemble anti-particles. However, there is a crucial difference. Unlike anti-particles, the mirror particles interact with ordinary particles predominately by gravity only. The three non-gravitational forces act on ordinary and mirror particles completely separately. For example, while ordinary photons (that is, ordinary light) interact with ordinary matter (which is just the microscopic picture of the electromagnetic force), they *do not* interact with mirror matter. Similarly, the 'mirror image' of this statement must also hold, that is, the mirror photon (that is, mirror light) interacts with mirror matter but does not interact with ordinary matter. The upshot is that we cannot see mirror photons because we are made of ordinary matter. The mirror photons would simply pass right through us without interacting at all!

The mirror symmetry does require though that the mirror photons interact with mirror electrons and mirror protons in exactly the same way in which ordinary photons interact with ordinary electrons and ordinary protons. A direct consequence of this is that a mirror atom made from mirror electrons and a mirror nucleus, composed of mirror protons and mirror neutrons can exist. In fact, mirror matter made from mirror atoms would also exist with exactly the same internal properties as ordinary matter, but would be completely invisible to us! If you had a rock made of mirror matter on your hand, it would simply fall through your hand and then through the Earth, and it would end up oscillating about the Earth's centre [*]. We can safely conclude that if there was a negligible amount of mirror matter in our solar system, we would hardly be aware of its existence at all. Thus, the *apparent* left-right asymmetry of the laws of nature may be due to the preponderance of ordinary matter in our solar system rather than due to a fundamental asymmetry in the laws themselves.

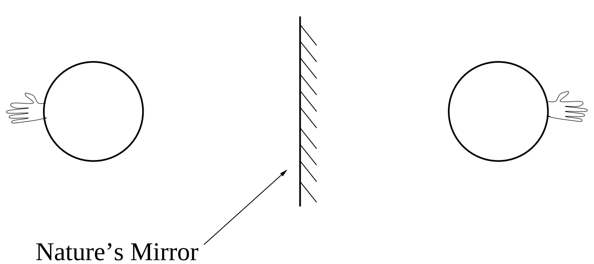
Do mirror particles really make the laws of physics left-right symmetric? Let us consider a simple and light-hearted 'thought experiment' involving again the Cobalt-60 decay. Imagine there was a mirror planet orbiting a mirror star in a distant part of our Universe (note that there is only one space-time – there is no 'mirror Universe'). Let's call this hypothetical planet 'Miros'. Miros is a planet made of mirror matter – atoms composed of mirror electrons and mirror protons and mirror neutrons. Miros is somewhat different to Earth though. It's a bit smaller with deeper oceans, but there is life on Miros. The people of Miros are a bit strange, they have very large feet and only have one eye – but they are very happy. They have wise leaders who would never dream of putting nuclear missiles in space and they realised very early the importance of reducing green house gases. On Miros a football team called 'Collingwood' often wins the football. Thus, Miros isn't much like Earth which just illustrates that microscopic symmetry of particle interactions does not translate into a macroscopic symmetry.

[*] Later I will discuss the possibility that a *new* type of interaction (or force) could exist coupling ordinary matter to mirror matter. If this is the case, it may actually be possible to pick up a mirror rock, although it would still be invisible. Clearly, the consequences of such a force are very important and it will be considered in chapter 5. However, in order to keep this introductory discussion as simple as possible, this possibility has been ignored.

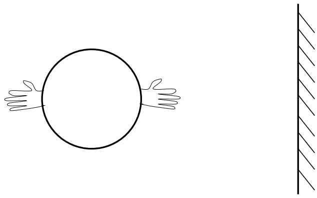
Anyway, our mirror matter friends on Miros realised the importance of pure science; their wise government always made sure that financial support was given to those mirror scientists who had a research record consisting of interesting and innovative ideas. One day someone on Miros had the idea that they should test whether the fundamental laws of nature are mirror symmetric or not. So they set up their Cobalt-60 experiment with a similar experimental set up as was done by people here on Earth in 1957. But what they found was something quite different. They found the mirror image result. That is, they found that the mirror electrons were mostly emitted from the decaying Cobalt-60 mirror nucleus in the opposite direction as was found here on Earth. Our mirror friends on Miros concluded that the laws of physics were right-handed.

The laws of physics cannot both be left-handed and right-handed. Ordinary particles form a left-handed sector, mirror particles form a right-handed sector. Taken together, neither left nor right is singled out, since ordinary and mirror particles are otherwise identical. (This is much like the letters 'b' and 'd'; 'b' represents the ordinary particles and interactions and 'd' the mirror particles and interactions). However, if mirror particles don't exist anywhere in the Universe then the laws of physics are indeed left-handed. Similarly if the Universe was full of mirror particles with no ordinary ones, then the laws of physics would be right-handed, but if both ordinary and mirror particles exist together then left-right symmetry is restored.

The basic geometric point is illustrated in the following diagram.

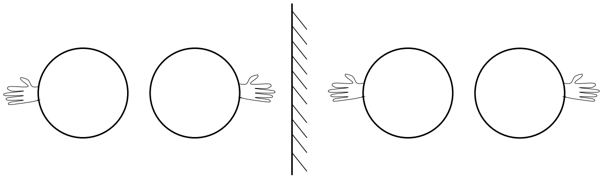


The left-hand side of this figure represents the interactions of the known elementary particles. The forces are mirror symmetric like a perfect sphere, except for the weak interaction, which is represented as a left hand. Also shown is nature's mirror - the vertical line down the middle. Clearly, the reflection is not the same as the original, signifying the fact that the interactions of the *known* particles are not mirror symmetric. If there were a right hand as well as a left hand then mirror symmetry would be unbroken without the need for new particles:



However, this doesn't correspond to nature since no right-handed weak interactions are seen in experiments.

There are two remaining possibilities: We can either chop the hand off – but this is too drastic and is therefore not shown. It corresponds to having no weak interactions at all, again in disagreement with observations. This last possibility consists of adding an entire new figure with the hand on the other side. Everything is doubled even the symmetric part, which is clearly mirror symmetric as indicated in the following diagram:



It is this last possibility that may correspond to nature.

While the mirror matter theory is simple, elegant, and the idea has been known for a long time, it is only in the past decade that experimental and observational evidence for mirror matter has grown to the point where a strong case can be made that it actually exists – and hence the motivation for this book. The evidence for mirror matter is diverse, ranging from studies of the lightest and most elusive