

# THE AUTOBIOGRAPHY OF LIGHT

George Grammatikakis



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George Grammatikakis  
Heraklion, Greece

*Translated by*  
Ben Petre  
Freelance Translator  
Heraklion, Greece

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## Preface

*The Autobiography of Light* was originally published in November 2005 by Crete University Press, one of the most reputable publishers in Greece. The first edition aroused lively interest and won critical acclaim, enjoying a long stay on the best-seller lists. That in turn led to the book being constantly reprinted, though its content and length remained virtually unchanged.

Yet one of the main features of our time, which in other respects holds many ills in store for humans and their lives, is that science continues to chart an impressive, almost unimpeded forward course. Physics and cosmology in particular, which are the general topics of this book, have made astonishing achievements and progress over the past two decades. Consequently, the prospect of publishing an English-language edition led to the need to enhance the content to make it fully reflect the present state of science.

*The Autobiography of Light* thus reaches out to a global audience enriched with all the latest developments in science, while standing every bit as proud of its record to date, accompanied by praise and well-loved by its readers. At all events, the book's new journey would not have been possible without the knowledge, diligence and hard work of Ben Petre, who translated *The Autobiography* into English and edited the bibliography. My colleague and friend Stefanos Trachanas was on hand, ever eager to discuss any difficulties large or small that arose. Invaluable input was provided by yet another colleague and friend, Vassilis Charmandaris, who meticulously combed through the English text and made apt and insightful observations. Thanks are also due

to my friend Pantelis Ikonomou, for useful conversations. It goes without saying that the biggest debt is to my family, for their unfailing support.

While this new edition stands out for its refreshed, updated form, it also retains the core that won it recognition. And that is the staggering realisation that light and its wondrous pathways have led science to its greatest accomplishments: to the theory of relativity, the quantum behaviour of the microcosm, and to modern views on the birth and evolution of the universe. At the same time, the book underscores the importance of light for life itself and for art, while also referring to the philosophical or religious views that have accompanied light down the course of centuries.

In sum, *The Autobiography of Light* uses simple language to describe the fascinating adventure of modern science, which has light as its unerring, revelatory guide. And that is why in the book's last chapter, the floor is metaphorically taken by primordial light itself, one of the greatest discoveries of modern science. In its own words, that light narrates its own aeons-long course through the universe, and its revelatory encounter with humankind. My hope is that my readers will be just as charmed as I have been by the infinite pathways of light, and that they will savour the pages of this book in their minds, and either in parallel or at some later stage in their hearts.

Heraklion, Greece

George Grammatikakis

## Prologue: The Author and Light

*He told me his book  
was called the Book of Sand  
because neither the book nor sand  
has any beginning or end*

—Jorge Luis Borges

Out of honesty towards readers, it ought to be confessed from the outset that the autobiography of light is, deep down, a love story. At some moment lost in time, light emerged unprompted at the centre of the author's life. Its colours and enigmatic nature, the infinity of its pathways and its iridescences seemed to possess an ineffable charm. So they were not long in conquering his soul. Just like that woman, if she existed—what pathway will she now be travelling on, I wonder—who appeared opposite him at some point, on the deck of a ship, and silently followed him from island to island and from sea to sea, for years and for centuries.

The truth is that I, the author, cannot pinpoint exactly when this adventure with light began, though I do remember that as a child I was afraid of nighttime. I could feel the night enveloping and threatening me, so I'd often stay awake waiting for the light. In the morning, redeeming light would come creeping in through crevices and chasing the night away, brightening as time passed and giving things identity. It was a calm, tender light, yet at other times—in summers—it would soon grow dazzling and merciless.

This game with light and the fear of nighttime went on over many years. It's still with me now, perhaps less acute. I usually only sleep a few hours, and even in the night I get up and wander around aimlessly. It's as if the arrival of light—like *her* arrival—pours balsam on the troubled ways of the soul.

I already knew a few things about light from school, though in a rather piecemeal way and without realising their importance: the laws of reflection and refraction, interference phenomena and the incomprehensible polarisation of light. But more tedious than all the rest was inflicted by an entire chapter of our *Optics* on lenses: convex and concave lenses, focal lengths, real or illusory images. Nearing the end of school, I believed that like other things in life, the light described in books had nothing to do with the light around us. There was just one day when a teacher spoke to us about photosynthesis. And the passion in his voice really did convince us that light had some important role to play in life itself.

Later, partly the trend for “sciences” and partly some fateful coincidences led me to the Physics Department at the University of Athens. There I tried to tease out some of the scientific concepts connected to light. Things definitely improved compared with school, yet rarely went beyond formalism and the surface. The vague expectation that university meant a distinct living and learning environment was rapidly confounded. Consequently, as is true of present-day students, my efforts focused on the demands made by exams. The rest of the time I preferred heading off to the cinema or theatre or spending hours browsing in bookshops.

In any case, I had come to understand that light was of fundamental significance to physics itself. To my surprise, I even realised that its nature was no different from that of radio waves or the X-rays used in medicine. Besides, the concept of “wave-particle duality”, which seemed crucial, posed a profound conundrum to us students. We couldn't easily get our heads around either that concept or any other elements of quantum physics then taught at university. As was true of so many other things, we had become trapped in the classical ideas of science. The shallow teaching methods and usually off-putting university textbooks were no help in overcoming them. As a result, my physics degree was accompanied by the bitter sense that I had barely tasted the quality of scientific knowledge.

On the other hand, my life often headed off along diverging but meaningful paths. The lustre of Left-wing ideas led me to the realms of poetry, cinema and artistic pursuits. All of a sudden, I discovered that the concept of light maintained a stable, powerful presence there too, loaded with all kinds of symbolism. One line by George Seferis—whose meaning I'm still not certain of—made a profound impression on me:



*Years ago you said: 'Deep down I am a matter of light.'*

Yet in the poetry of Elytis, who had yet to gain his present renown, light emerged with force and continual doublings-back.

From some point on, then, my relationship with light kept taking two parallel paths. The first, that of science, exacting and yet enchanting, led to a constant deepening of knowledge, but was fraught with major difficulties. The second road led through art, poetry or philosophy, trying to probe hidden meanings and significations. Of course, it didn't take me long to see that while the two roads were parallel, they did intersect and had common points. Besides, the general theory of relativity had shown that the true geometry of the universe was non-Euclidean and that parallel straight lines did intersect.

It is perhaps superfluous to stress that the road of science called for method and strenuous effort. Finding this out was a torment when I began post-graduate studies at Imperial College London. I discovered that knowledge of modern physics—of relativity, quantum mechanics and elementary particles—was necessary for the nature of light to emerge with any clarity. Thus, the wave-particle duality characterising light was a more general and inviolable principle of quantum mechanics. By contrast, the laws of reflection and refraction that had, among other things, poisoned our schooldays, simply expressed one of light's key capabilities: in moving from one point to another, it always chose the route that took the least time!

Back then the thing at the forefront of physics research was one of the subject's age-old problems: the structure of matter and its fundamental particles. More out of intuition than knowledge, that was the area I chose to do my doctorate in. It was already obvious that the protons and neutrons making up the nucleus of an atom were not the most elementary constituents of matter. An entire world of particles was emerging from experiments and theoretical research. In successive transformations or combinations, they participated in the everlasting processes of the universe. Lone and proud among them stood the photon, i.e. the fundamental unit of light.

In this world of scientific research, seemingly without end or beginning, I have spent a great part of my life. I worked as a researcher in England and, having returned to Greece—it was 1973—at the Demokritos Institute of Nuclear and Particle Physics in Athens. But being complex and costly, necessary experiments were always carried out at the European Organisation for Nuclear Research in Geneva, also known as CERN. That is the site of large accelerators—even more powerful ones are now under construction—where elementary particles are accelerated to enormous speeds and then left to collide with each other. Like a child smashing a toy with a hammer, these

collisions can reveal the internal structure of matter, and shed light on the interactions ruling its elementary level.

Experimental needs meant I had to make plenty of trips and often spend time in Geneva. Later on, I was even invited to work there for an extended period. The need to understand the nature of light as much as possible alleviated homesickness, as did the intensity of research work. In fact, I enjoyed observing the constant transformations of photons into electrons detected by special sensors. It may really seem incredible, but light is converted into matter!

As my knowledge increased, the scientific side of light gained a more distinct form in my mind: light was an electromagnetic wave propagated at colossal speed, yet was simultaneously particulate in nature. The photon, the fundamental particle of light, had a place all of its own among the matter and energy particles making up the world. A neat, detailed theory known as quantum electrodynamics had already been formulated, describing the interactions between photons and matter. According to it, the photon is a kind of messenger exchanged between matter particles, creating electromagnetic forces. In fact, the idea of exchange was later extended to interpret the remaining forces. In science just as elsewhere, light has always shown the way!

Anyway, for as many years as I was forced to live far from Greece, the longing for Greek light was torture. Besides, there was also the longing for the one—what pathways of light will she be travelling on now?—who accompanied my thought and dreams. This double longing led to constant wavering in my feelings. The expectation of returning often mingled with fears over what meaning it had.

Here a break is needed, as it's the moment in around 1980 when life, and thus my preoccupation with light, reached a major turning point. The University of Crete had just begun operation, and I was called on to participate in organising it and teaching in the Physics Department. A short while later I was elected professor and left the Demokritos Institute for good. As for my scientific research work, I now had few opportunities to work on the CERN experiments and large accelerators. All the same, one of the most paradoxical and interesting “fundamental” particles had begun to preoccupy the Greek scientific community: the neutrino. Its mass was infinitesimal, its charge—like that of the photon—was zero and, being incredibly penetrative, it could pass through the entire Earth without difficulty. A grand and difficult experiment that would become known by the acronym NESTOR (Neutrino Extended Submarine Telescope with Oceanographic Research) aimed to detect ghostly neutrinos in the depths of the sea at Pylos, as they arrived there from distant galaxies or stellar explosions. I began collaborating

with the experiment, which was inspired and coordinated by Prof. Leonidas Resvanis at the University of Athens. At the same time, our attempt to detect the neutrino in the depths of the sea, where cosmic radiation could not reach, had a transcendental dimension to it that mitigated the experiment's difficulties.

There is of course no need to stress that in this new university-focused cycle in my life, too, I felt the need to understand light as much as possible. Indeed, I now had some unexpected assistance, which was simultaneously a torment: my students. When I was teaching electromagnetism or the theory of relativity—which are of fundamental importance to the theory of light—the questions they asked often put me on the spot. More than a few times I made a diplomatic sidestep. All the same, the experience of teaching reinforced the suspicion from my student years that light and its behaviour were the cornerstones of physics and its major accomplishments. It's characteristic that the receding of the galaxies was revealed thanks to their light; and that the discovery of "primordial" light confirmed that the universe was created by a Big Bang. As well as the evolution of life on Earth, this impressive flowering of cosmology was described in my first book, *Berenice's Hair*, which proved surprisingly popular.

Light, then, proved to be an invaluable messenger of the universe's secrets. So the irresistible attraction I had been feeling for years filled me with pride; but it also contained traces of jealousy, which even then seemed inexcusable.

As for the other side of light, to do with art or its games with people and landscapes, it goes without saying that I let down my defences to an allure that knew no bounds. So it was no exaggeration when, at the beginning of this prologue (or perhaps confession?) I wrote that this book about light is, deep down, a love story. Science, meaning my rational mind, was constantly striving to understand light, to analyse its behaviour via laws and equations. Yet the presence of light itself—as with every great love—was bidding for unconditional acceptance, a surrender to passion and the allure of the uninterpretable. Perhaps that's why that woman, who had accompanied my wanderings for centuries, remained silent in the face of my insistence on guessing her intentions. "But," wrote Kafka, "the Sirens have an even more terrible weapon than song: their silence."

In any event, I discovered the true significance of light in our life and feelings when, as I have already related, the migrations of the soul led me to Greece for good. In England and the European countries I had lived in up until then, the light seemed as if it were gasping or being persecuted by some unknown, invisible enemy. But on my return to Greece, I got the feeling I had rediscovered light. "Greek light," wrote Henry Moore, "is, as

everyone says, something that you cannot imagine unless you experience it. In England, half the light, in some way, is absorbed by objects. However, in Greece, objects seem to give off light, as though illuminating themselves from within.” I genuinely began to be convinced that, as our teachers and poets have long stressed, light is entwined with Greece and its destiny. And even more so that I bore the expectation and need of light within me.

In that way, travels in my own country now took on a different, rather paradoxical content: I felt that I was reliving Greece as multiple quests for light, thanks too to the varied, revelatory forms it assumed. Really. In the islands of the Aegean and in Epirus, in Attica or the Ionian Sea, Greek light always laid its own peculiarities bare, lending a sense of identity to the area’s inhabitants and geography. In fact, I was not long in expanding my findings. Here in Greece, the clarity of light has determined the character not only of the landscape, but also of our intellectual quests. An imaginary line starting from the Apollonian light of antiquity ran through the phrase “Come receive the light” in the Orthodox liturgy of the Resurrection, and reached down to Odysseas Elytis’ “Worthy is the Light”. As the poet himself notes, “Light and history in Greece are one and the same thing... the one replicates the other, the one interprets and vindicates the other, even the very void that is black.”

So it is, then: in Greece, light does not simply relay images and faces, it is not merely the messenger of the universe. It is elevated to the level of creator, moulding and highlighting in some magic way.

In 1990, my election as chancellor at the University of Crete radically altered my way of life and everything in it. In the intensity and loneliness of the position, the light was always there as anguish and solace, meaning and refutation. That phrase by Seferis, “deep down I am a matter of light”, which had hounded me since my student years, was now gaining a clearer content.

The kindness of my colleagues and students led me to a second term of office as chancellor. When it came to an end, *Cosmic Writings* came out. Like *Berenice’s Hair*, this second and more personal book was much loved by readers. But I had already developed a tantalising desire to write a book about light. The idea didn’t move along much, though, as there was no lack of new challenges. At around the same time, the Greek Broadcasting Corporation decided to make a television series out of *Berenice’s Hair*; the filming took time and a lot of travelling which, as I thought at least, was distracting me from the idea behind the book. That turned out not to be the case. Light continued to accompany my quests and my thoughts. I remember that once we had to spend the night with the television crew on Delos. At first, we witnessed the games played by light at dusk, and then the gentle light of

nighttime spread everywhere. The only thing accompanying the sleepless wait for morning was the light of the stars and the sounds of waves dying on the shore. It was as if time had stood still. Like then, like always, when the expectation of her cancelled out any other thought or intention. When at some point the evocative morning light of Delos broke, inscrutable and ineffable, I simply abandoned myself to its allure. The dazzling sun soon rose, burning our eyes and the landscape. Everything I had heard about the miracles of light on the sacred isle paled in the face of reality—and what is reality, one wonders.

From very far back, light has been a symbol encapsulating the good in the world. To the Persians, for instance, Ahura was the god of light and represented beauty, wisdom and kindness. Conversely, Ahriman was the lord of darkness and the personification of evil. According to Egyptian mythology, the Sun in the form of the god Ra was the creator of the world, who touched Earth and gave birth to its elements. Of those elements, fire and water played a leading role. The stars were believed to be the souls of dead kings who ascended into heaven to be united with the Sun god or join his retinue.

Later on, in the more refined Greek world, sun worship was associated with Apollo. As an entity, light has a substantial presence in theories of the universe's origins. According to Hesiod's *Theogony*—the earliest depiction of the Cosmos, and one of the finest—the leading trio of creation consisted of Chaos, Earth and Love. Night and Darkness were born of Chaos, and from their union came the opposites, Day and Aether. And so is expressed the standard pre-scientific knowledge that night is succeeded by day, and darkness gives way to light.

So time went by. The book writing was progressing haphazardly. First one thing would crop up, then another. The passing of time was in any case a devious force, always putting me under pressure. In despair, I would count the things I wanted to finish, while there were others I would have liked to start from scratch. But I was afraid there wasn't much time left.

This curious relationship with time may explain the interest in old pocket watches that I, the author, gained at some stage. Each watch has its own unique beauty, which seems untouched by the passage of time. Besides, while its lifespan often runs into centuries, the wondrous mechanism doesn't show substantial signs of wear either. Yet how many times might it have changed hands; how many life stories might it have witnessed! As I carefully wound the watches and hung them here and there with their wonderful chains, I had the sense that time did not exist. That it was breaking down into dozens of faces.

All the same, real time continued to flow relentlessly on. A new challenge—to take on the Ionian University as president of its Governing Board—made the prospect of the book recede again. On the other hand, it would have been difficult to decline this fruitful meeting with Ionian light. Sure enough, Corfu and the islands of the Ionian Sea had their own phantasmagorias of light to show off; and I would simply let down my defences to its allure. At the other end of the same geographic arc, at Pylos, the NESTOR experiment was continuing its titanic efforts to detect the neutrino. To that end, a sensitive electronic device resembling an outsized starfish had been submerged for trial purposes in the depths of the sea. As neutrino detection would—like light—yield important information on the stars and their evolution, and perhaps also on the birth of the universe itself, that major prospect buoyed up all of us taking part. Yet the demands and difficulties of the experiment often seemed intractable, and it looked as if a stop to it was not far off.

Though it may no longer seem so anymore, the paradoxical thing was that while time and commitments never ceased to hound me, writing the book kept on gaining momentum. It was solidifying within me both as a wish and as a kind of duty. As I believed at the outset, the reasons for that paradoxical need had a rationalism to them, in a good sense. I kept thinking that light was an all-important presence in our lives, so the scientific dimension to it would be of great interest to readers.

Besides, in science itself, light really does have a place of its own. It is difficult to find areas of knowledge untouched by its multifaceted presence. For physics in particular, to investigate light is to depict the history of the subject itself. A history that doesn't head in a straight line, but rather in a broken one: achievements go hand in hand with dissent, accomplishments with failures.

At any rate, it's worth underlining that just like many other things in life and in the mind, the concept of light seems deceptively familiar and simple. I hope you will be disabused of this delusion from the very first pages of this book. Like that woman who kept accompanying me on neverending wonderings, light persistently hides its true face, troubling our mind and soul with its secrets. Readers, careful readers, should perhaps ask themselves whether the same might not apply to other supposedly self-evident truths, and whether it might not be time to question the ease with which we arrive at assessments and conclusions. If the constant endeavour to understand light teaches anything, it is how often certainties dissolve, and how all kinds of dogmatism grow dangerous. I only hope that a sense of constant searching for an uncertain truth can touch readers with its beneficial power. They will then be

less exposed to the easy and the ephemeral, to superficial judgements or the confusion over values that are symptoms of today's enfeebled culture.

So there were powerful objective reasons why it was worth writing a book about light. Besides, in *Berenice's Hair* I had noted that "a book is always an attempt to communicate. Whether the author is attempting to communicate with readers or themselves may not particularly matter. What does matter is when the communication leaves some internal traces on the author or the reader." It is obvious, I think, that the wondrous adventure of light has left internal traces on me, the author; it's those feelings I'm hoping to share with readers. But the time has come to confess that those traces have not only had to do with the importance of light or scientific understanding of it. As I have come to realise over time, there is also another substantial reason: it's that the nature of light is hallmarked by certain preposterous attributes, certain unique graces.

I want to be honest. From the time when the unexpected secrets hidden by light were revealed to my mind and soul, the attraction I felt grew immeasurable. That explains the fact that between the eddies of my life, I would always try to snatch some time, to move one chapter on, to correct another one. And that even in the small hours of the night, when the tidings of time and fear arrive, I would find myself wrestling with words, putting down on paper what readers will come across in the pages to follow.

Besides, we said from the outset that deep down, the autobiography of light is a love story. And like every such story, in its depths, it hides moments of serenity or passion, confirmation or refutation, grandeur or despair. In speaking of light, one speaks of the world and its secrets. Likewise—and this is perhaps more serious—one touches on some anxieties of the soul and its hidden questions.

Yet just as is true of any great love, my attraction towards light was accompanied by an unspoken jealousy. Or, to be more precise, there was a kind of admiration that also hid elements of jealousy within it. In any case, doesn't jealousy go hand in hand with love, often clouding our reason and our feelings?

In its pages, then, this book will seek out the nature of light, describing its behaviour as far as possible. That way some of its important gifts will emerge. These gained particular importance the more I, the author—and perhaps also the reader—learned about myself. So my jealousy of light was at least grounded in something, it was less reprehensible or base.

Besides, the way the book got its title seems far from random. At some point, that woman who had been following my wanderings for centuries, from island to island and from sea to sea, drew closer in the faint starlight

and came up to me. This time her presence was no illusion. I clearly saw the melancholy in her eyes and felt the touch of her hands on my own face. “Light,” she said, “comes from very far off. From a Space where there was no space, and from a Time when there was no time. Ever since then it has enveloped the Cosmos and highlighted its every expression.” She looked at me tenderly. “So the autobiography of light,” she went on, “is my autobiography too. And it will never cease to be written for as long as I exist. As long as we exist,” she whispered, and began to draw away again. In my confusion and passion, I didn’t know whether it was her speaking or light itself.

That’s how it happened, at any rate, and how the book got its title: *The Autobiography of Light*.



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## About the Author

**George Grammatikakis** (1939–2023) Born in Heraklion, Crete, George Grammatikakis read Physics at the University of Athens before moving on to postgraduate work and research at Imperial College London, where he received his PhD in 1973. On returning to Greece he joined the staff at the Demokritos National Centre for Scientific Research, later working at the European Organisation for Nuclear Research (CERN) in Geneva. He had a key role to play in organising the newly founded University of Crete, where he was appointed professor of Physics, and subsequently professor emeritus. He was elected university chancellor for two terms (1990–1996), later going on to serve for four years as Chairman of the Governing Board at the University of the Ionian. Additionally, he participated in European Union international expert committees on education and research prospects.

His research interests centred on the structure of matter and cosmology, linking the microcosm to the macrocosm. As a visiting professor at Harvard University (1989–1990), he also worked on the history of science.

A versatile personality, he was a member of the Governing Board of the Greek Broadcasting Corporation, president of the Nikos Kazantzakis Museum on Crete and vice-president of the Greek National Opera. His belief both in bridging art and science and the importance of popularising science found a range of outlets. These ranged from press articles to artistic events featuring science narratives, images and music (including acclaimed performances in Athens and Thessaloniki based on *The Autobiography of Light*). As well as editing and producing successful public television documentaries,

he created an award-winning series based on his book *Berenice's Hair*. The interrelationship between science, art and all manifestations of human culture permeated everything in his enduringly popular work, leading to multiple reprintings of his five books.

As an actively involved citizen with a genuine interest in people and public life, he was elected MEP in the 2014 European Parliament election, serving as a member of the Parliamentary Committee for Culture and Education, as well as the Committee for the Environment.

George Grammatikakis won numerous accolades and prizes in Greece, and was made a Knight of the Order of Academic Palms by the French Republic.



# 1

## Light Gambols Through History

### 1.1 The Illusion of Familiarity

Light fills the entire universe. There is light at the most distant points in space, in the deep silence of night, in the faces and landscapes of our world. Yet its presence is only indirectly perceptible. We cannot see light itself. Via light we can see objects, their colours or how they move, as our brain synthesizes them. It is as if nature wished to protect us: if light itself were perceptible the way it arrives every moment and from all directions, it would overload our brain functions. The suspicion that something comes between us and the surrounding world arises from light's often paradoxical behaviour, like the tricks played by sunlight in the atmosphere, or an oar that appears to bend in seawater.

On the other hand, we sense that light is very familiar, making up the basic tissue of our life. In some sense we live in light, create under its wing, owe our existence to it. The relationship between humans and light is as essential as that between fish and water. Without light, neither human beings nor their life is conceivable. Apart from those scarred by misfortune, humans only spend moments of their life acting in the absence of light, devoid of its beneficial contribution. Besides, as we learnt in our schooldays, the wondrous process of photosynthesis is what maintains the cycle of life.

So it is that darkness—the absence of light—is quite rightly linked to fears, whether grounded or ungrounded, to death itself, and to the sinister powers in our own selves and in nature. On the other hand, thanks precisely to its special meaning, the word 'light' is loaded with symbolism. "Light of my life" is what lovers call each other; we Greeks never tire of repeating that Ancient

Greek civilisation was “a radiant beacon” for humanity; and in celebrating the resurrection on Easter night, the Orthodox faithful chant: “Come receive the light, from the light that is never overtaken by night”.

Down the course of the centuries, light has always been linked to wisdom and truth, whereas darkness represents Evil. And while this dichotomy is typical of the high points in the mythology and culture of every era, eighteenth century Europe was dominated by a broad intellectual and philosophical movement that was, in characteristic fashion, to be named the Enlightenment. The Enlightenment expressed faith in progress and the potential for humans to attain perfection, defended political freedoms and tolerance of others’ convictions, and reacted against the irrational interpretation of the world and its submission to religious dogmas. Enlightenment ideas gained powerful political and social support, thus exercising considerable influence—something which, sadly, they still need to do!

For human beings, then, light is a basic precondition that enables them to perceive space and motion; it also enables them to perceive the colours and shape of objects. Light reveals the world, yet is also its creator.

It is true that the human eye often has the illusion that the sky is bright of its own accord, and that the brightness of the Earth and material bodies is a quality inherent in them, which is only lost in the dark. In reality, however, light travels in a dark universe before ending up on Earth and illuminating its sky. It is worth noting that almost all the information concerning the innumerable galaxies and stars reaches us in the form of light.

Besides, on a deeper level our world is made up of light and matter. The perennial interaction and interplay between the two often lie behind the world of phenomena. Indeed, as modern physics has revealed, light itself can be transformed into matter. Incredible as it may sound, this transformation is a run-of-the-mill experience in large research laboratories. What is more, modern cosmology maintains that the orgiastic transformation of light into matter particles—and vice-versa—dominated the first moments of creation.

Our life is not only bathed in natural light, which derives mainly from the sun. With fire as their distant, invaluable ancestor, various artificial light sources are now of vital importance to people and their activities. The production of electric light was obviously one important step that radically changed our social and personal habits. And in the laser, modern life is feeling the ever-increasing impact of another source of artificial light. As concentrated, high-intensity light, laser beams are already working wonders in everyday life, medicine and industry.

Yet it is not simply the physical presence of light nor its many useful forms that renders it our inseparable companion. It is also a central reference point

in art. With the aid of light, the visual arts reproduce shapes, masses and forms. Since ancient times, the evocative power of colour has set its seal on masterpieces on vases and frescoes. Besides, two modern art forms—photography and the cinema—are founded on recording the games light plays on the people and things in our world.

The everlasting presence of light in our world and life leads to the grand illusion that nature itself is simple, and that its attributes and deeper structure are easy to grasp. Thus, down the course of the centuries, philosophers and major thinkers from Leucippus to Goethe and from Plato to Leonardo da Vinci formulated views on light and the operation of vision. Though they often showed intellectual ability and daring, these views now seem naive. To a great extent, the same fate was reserved for the proper scientific investigation of light that flourished particularly from the seventeenth century on, with the scientific revolution. Though the progress made was undeniable, it was marked by doubt and dispute. Light has proved highly resistant to comprehension: the moment one of its properties is discerned, another more important one appears; just when the end seems in sight, it draws further away again.

Light, then, is the basic key to comprehending the universe itself. This truth, which marks the entire course of natural science, reached its apotheosis in the twentieth century: the theory of relativity; the establishment of quantum physics; the discovery that the universe is expanding; laser beams and cosmic microwave radiation, to mention but a few of the important steps made by modern science, are rooted in the sustained effort to comprehend light.

At the same time, the technological culture that is both our pride and a threat to our existence has swathed every human activity in electromagnetic waves; and all over the planet it has created a communications and information web unimaginable only yesterday. Electromagnetic waves, too, are an invisible side to light. Equating the two was once again a wondrous step in a long, eventful quest.

Yet though light as a multi-faceted entity has come to dominate both everyday life and science, questions still remain as to its true nature. Familiarity with light and its colours leads to facile illusions. These are instructive nonetheless, as they reveal the simplistic ease often typical of the way we think. So there is no end in sight for the wonderful adventure of light, which began so long ago. It can not only boast of great moments and crucial errors, but also of the constant attempt to search further. It has led us to an understanding of the cosmos and revealed its hidden dimensions, but has also pointed out our limits, imposing a degree of humility on us. It is



worth noting that in the closing years of his life, having triumphantly introduced photons as the fundamental “quanta” (grains) of light, Einstein himself admitted his inability to grasp their true nature.

In the broader sense, it is thus didactic to make at least brief reference to the history of light. This history cannot be isolated from the prevailing atmosphere in each era, or from its broader cultural coordinates. Indeed, quite the opposite. The history of light is bound up with the course of humanity and its achievements, fears, prejudices and anxieties. In his wonderful *Preface to the Treatise on Vacuum*, Blaise Pascal observes: “Thence it is that by an especial prerogative, not only does each man advance from day to day in the sciences, but all mankind together make continual progress in proportion as the world grows older, since the same thing happens in the succession of men as in the different ages of single individuals. So that the whole succession of men, during the course of many ages, should be considered as a single man who subsists forever and learns continually [...]”<sup>1</sup>

So light’s gambols through history are gambols by humankind itself—and that is something that you, dear reader, should always bear in mind.

## 1.2 Flashes of Light in Antiquity

Long before it became an object of scientific enquiry, light and its sources were accorded divine status. The world’s mythologies boast images and myths beyond compare, telling of the sun and the moon, the stars or fire. The sun was the source of life, symbolising the creative power of nature and acting as man’s guide to the hours and seasons.

From very early on, light was a symbol that condensed all the elements of good in the world. To the Persians, for instance, Ahura was the god of light and represented beauty, wisdom and benevolence. Ariman, on the other hand, was the lord of darkness and the personification of evil. According to Egyptian mythology, the sun in the form of the god Ra was the creator of the world, who touched the Earth and gave birth to its elements. Of these, fire and moisture held pride of place. The stars were believed to be the souls of the dead kings, who ascended into heaven to become one with the Sun God or to join his retinue.

Later, in the more sophisticated Greek world, sun worship became associated with Apollo. Light as an entity had a significant presence in theories of cosmology. According to Hesiod’s *Theogony*—the earliest depiction of the Cosmos, and one of the most poetic—the primordial trinity of creation comprised Chaos, Gaia (Earth) and Eros. Night and Erebus were born

of Chaos, and from their union sprung their opposites, Day and Aether. This was an expression of the established pre-scientific knowledge that day succeeds night, and that darkness gives way to light.

The significance of light is also underlined by a beautiful image encountered in the work of the comic poet Antiphanes: "Of Night and Silence came Chaos, and then of Chaos and Night Love, and of Love Light, and of Light the first generation of the gods."<sup>2</sup> The idea that light derives from Love, and the gods in turn from it, would be difficult to dispute even today! In any case, the uniqueness of Greek light emerges from as early as Homeric times. "Only in Homer's Greece," notes Roberto Calasso, "does the cry of the warrior who begs Zeus that he may be killed in the light make any sense: 'Destroy us in the light, since such is your pleasure.' The light will not serve to escape death but to usher it in. A death in the gloom of the fog would already be a fragment of the sorrowful afterlife, all weakness and vacillation, whereas a death in the light is a last instant of clarity."<sup>3</sup>

Lastly, it is worth stressing that fire, which is both a tool and light, was what Prometheus chose as an invaluable gift to humans. And since it signifies the dawn of technical civilisation, the associated myth is timeless in its symbolism.

Nevertheless, any attempt to provide an account of ancient peoples' myths concerning the Sun and light seems futile and in vain, such is their wealth and imagination. And however much it boosts our ethnocentric sense of conceit, the truth remains that the first ideas concerning the true nature of light are encountered in Ancient Greece. They are philosophical in origin, but often contain elements of science. In any case, it is well known that Ancient Greek "philosophy" encompassed all branches of learning, and that philosophers were universal thinkers, free of compartmentalised knowledge. As the historian of science C. Gillispie stresses: "Of all the triumphs of the speculative genius of Greece, the most unexpected, the most truly novel, was precisely its rational conception of the cosmos as an orderly whole working by laws discoverable in thought. The Greek transition from myth to knowledge was the origin of science as of philosophy. Indeed, knowledge of nature formed part of philosophy until they parted company in the scientific revolution of the seventeenth century."<sup>4</sup>

The attempt to interpret the world via logical argumentation and reasoning had its beginnings on the shores of Ionia. Miletus, a city both wealthy and in contact with the cultures of the East, was in the sixth century AD a hub of innovative ideas that were rapidly disseminated throughout the Greek world. Great thinkers known as the Presocratics developed the first theories on the creation of the world and the nature of the senses, making frequent references

to light and vision. As stressed by Constantine Vamvacas, a leading scholar of their works, “The goal of the Presocratics is ambitious. Their aim is to *comprehend* not to describe nature. They are so acute and visionary as to perceive that any involvement with partial, experimental details would necessarily mean diversion from their sole end, which is to *apperceive* the cosmos in its *wholeness*.”<sup>5</sup>

It should be noted that very early on, Parmenides made systematic use of light and nighttime to account for physical phenomena and to build his own cosmological edifice. However, the few surviving fragments of his work are too insufficient and opaque to permit reconstruction of his complex cosmological system, which also included “annuli” or rings of light and darkness. The presence of light in Parmenides’ theories is attested to by one of the most beautiful lines in Greek literature:

νυκτιφάεξ περί γαίαν αλῶμενον  
αλλότριοιον φως  
“Astray over earth / Bright in darkness /  
Its light also a wandering foreigner”<sup>6</sup>

which, in free translation, refers to the light that shines at night and wanders around the Earth, coming from foreign parts.

So the history of optics begins with works of natural philosophy. Empedocles, Leucippus and Democritus are pre-eminent among the Presocratics who concerned themselves with the nature of light and the operation of vision. They were all alive in the mid-fifth century, as the “Greek miracle” was approaching its apogee: the Parthenon had begun to rise into the light of Attica; the tragedies of Aeschylus and Sophocles were being performed in the theatres; and a humble man named Socrates was teaching in the Athenian Agora. As this brilliant era drew to a close, Plato was impatiently awaiting his moment.

The philosophical ideas of Empedocles were to have a major influence on his successors. He himself was a curious combination of philosopher, mystic and shaman. His ideas on the operation of vision overturned the previous Pythagorean view, which asserted that optical rays were emitted from the eyes and reflected off objects, creating their image. By contrast, Empedocles focused his attention on objects themselves: light rays “emanate” from their surface, conveying information about them. A kind of optical sensor extending from the eye then picks up the information and forms the object’s image. In other words, there is a clear analogy with the finger, which feels a body and senses its shape. The theory of emanations was in any case trying to

provide an interpretation for all the senses; and it argues that we feel something when it fits into the pores of each individual sense. It is also worth noting that according to Empedocles, sunlight is made up of particles, and arrives first between Earth and the heavens before reaching us. Its motion escapes us because it occurs at enormous speed.

The theory of emanations was accepted and elaborated by Leucippus and Democritus, the atomist philosophers. They held that under the influence of light, the surface of objects constantly generates extremely thin veils of matter, known as *eidola* or images. These move continually at immense speed in all directions. They do maintain their shape, however, and as they reach the eye at brief intervals, they create a sense of continuity in a changing image.

Given that the atomist philosophers endorsed the theory of emanations, it follows that they would have linked it to the idea of atoms, which was one of the most brilliant conceptions in Ancient Greek thought. So does a body appear red because it emits red atoms? The answer is negative. Colour does not number among the primary attributes of atoms, like their size or shape. The atoms of *eidola* simply touch our eye in such a way as to create the impression of red. "By convention sweet and by convention bitter, by convention hot, by convention cold, by convention colour; but in reality atoms and void,"<sup>7</sup> Democritus stresses. Thus, atoms themselves only have few attributes; and the image we see on receiving them is created by our own selves.

Perceptions of the role played by atomic particles in conveying the sense of hearing or sight remained dominant until the Renaissance. The fact that, a century after Democritus, atomic theory and the idea of *eidola* were accepted by Epicurus played an important role in their dissemination. His views are summed up in the following excerpt from one of his letters: "There are patterns of shapes similar to those of solid bodies but quite different from any appearance we know on account of their fine-grained quality. Because it is not beyond the power of nature to make such subtly refined lengths of space within the all-encompassing <empty space> nor to make such skilfully fine-tuned arrangements that can craft the hollow and smooth surfaces; nor to make outflows maintain the same <coordinate> positions on two dimensions, which they had analogously when they were in the solid bodies. And we call such patterns images [*eidola*]. As their movement through space meets no countervailing resistance from bodies that could rebuff them, these images can complete any conceivable distance in an inconceivably short period of time."<sup>8</sup>

It would appear that the workings of a world that consisted of impersonal, neutral atoms was consistent with Epicurus' aversion to the abstract and the

supernatural. “It is impossible to be released from fear about the most important things for one who, not having adequate knowledge as to what the nature of the whole is, is trying to second-guess this or that in accordance with the <traditional> fairy tales.”<sup>9</sup>

Epicurean perceptions of both the senses and atomic theory are encountered at length in one of the famed epics of Roman times—Lucretius’ *De rerum natura*, written circa 50 AD. The fact that it was written in Latin is of particular importance. The Greek world was in decline, and the Latin language began to gain wide currency in educated circles. According to Lucretius, light is a necessary condition for us to perceive *images*, which are formed of atoms. That light derives from the sun, the moon and various other “fires”, and is a specific substance behaving in its own particular way.

The epic by Lucretius envisages the universe as a combination of atoms but also contains elements of evolutionary theory. Interestingly, it was greatly admired and constantly copied, possibly because Lucretius’ materialistic and dialectic outlook and his Epicurean influences opposed Christian dogmatism, which had begun to gain ascendancy.

That being said, it is worth noting that just like human history, the history of science has often been hijacked by dogmatic views. Fortunately, once experiments became established, science found a way to outflank them. Testing ideas by experiment is an incontestable strength of science, and a hallmark of its progress. Dogmas and revealed truths have always been a source of human suffering and arrogance.

### 1.3 The Platonic View of the World

In the second half of the fifth century BC there was a marked shift in philosophy, towards the human individual and the problems of life. This radical shift articulated the reaction of common sense thinking against the world as presented by natural philosophers, which was remote and unintelligible. The ascendancy of a new class—the sophists—who earned their living by guiding people in practical matters, was the result of this more general human-centred shift. What set the sophists apart was a scepticism bordering on irony with regard to absolute values and knowledge.

Into this transitional world stepped Socrates, who attempted to restore the damaged credibility of philosophy and moral values. On the other hand, his gifted pupil Plato made it his life’s work to disseminate and advance Socratic teaching and its moral lessons, which had hitherto been oral. Following the death of Socrates and extensive, adventurous peregrinations, Plato returned

to Athens. There he founded a kind of school of philosophy (Fig. 1.1), the famed Academy. He wrote around thirty dialogues centred on metaphysics, ethics and politics.

It is characteristic that, as the leading twentieth century philosopher Alfred Whitehead believed, all of Western philosophy after Plato could be read as mere footnotes. For all its apparent hyperbole, this comment reflects both the historical weight and enduring quality of Plato's work. Rather than acting as an authority, he motivates people to search for the truth, asking successive questions and attempting to upset pre-existing certainties. He thus chooses Socrates as the central figure in his dialogues, not simply by way of reference to his teacher, but so as to reveal the delusion of the senses and phenomena via the Socratic method known as maieutics. In unparalleled fashion, his work reveals the dialectical course to eternal, archetypal ideas of goodness, beauty and truth, which are only encountered as imperfect imitations in the everyday world.

Yet as far as light and the operation of vision are concerned, Plato has little to add to that held by Empedocles and the atomist philosophers. His account represents a fuller synthesis nonetheless, and he believes that the light issuing from the eye is of equal importance to the light of the sun.



**Fig. 1.1** Raphael's famed fresco *The School of Athens* (1511) in the Apostolic Palace, Vatican City, representing Greek philosophy (Vatican City Museums/PD)