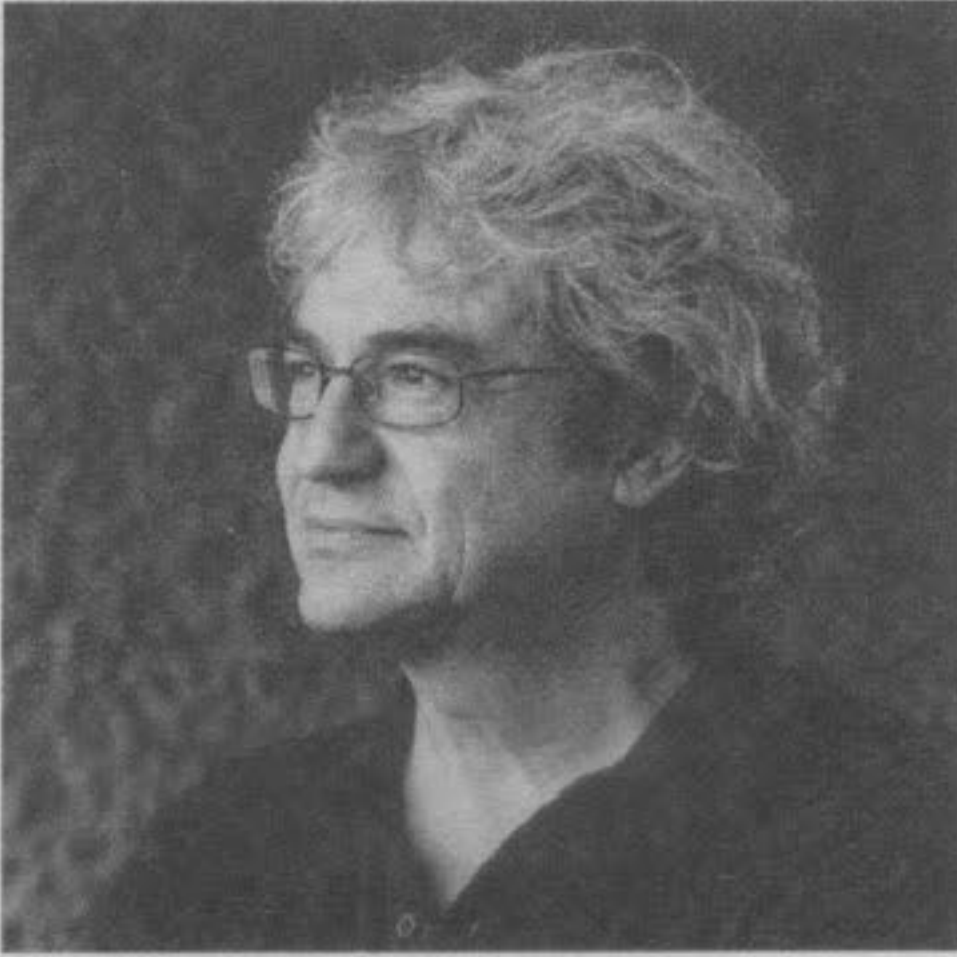


ONE IDEA, MORE THAN ANY
OTHER, HAS TRANSFORMED
OUR UNDERSTANDING
OF THE FABRIC OF REALITY:
QUANTUM PHYSICS.

In June 1925, twenty-three-year-old **Werner Heisenberg**, suffering from hay fever, retreated to a treeless, wind-battered island in the North Sea called Helgoland. It was there that he came up with the key insight behind quantum mechanics. A century later, this theory has given us modern technology and nuclear energy but remains disconcerting, enigmatic and fiercely debated.

Helgoland is the story of quantum physics and its bright young founders, who were to become some of the most famous Nobel winners. It is a celebration of youthful rebellion and intellectual revolution. It is a transformative journey. Here Carlo Rovelli, one of our most influential thinkers, illuminates competing interpretations and offers his own original theory: the 'relational' interpretation of quantum mechanics, where the world is fundamentally made of relations and events rather than permanent substances. Where we, as every other thing around us, exist in our interactions with one another, in a never-ending game of mirrors.

A riveting voyage, full of wonder and delight, *Helgoland* revolutionizes our understanding of the universe and our place in it.



Carlo Rovelli is a theoretical physicist who has made significant contributions to the physics of space and time. He has worked in Italy and the US, and is currently directing the quantum gravity research group of the Centre de physique théorique in Marseille, France. His books *Seven Brief Lessons on Physics*, *The Order of Time* and *Reality Is Not What It Seems* are international bestsellers which have been translated into forty-three languages.

Without Foundation? Nāgārjuna

This way of understanding the central discovery of quantum mechanics is rooted in the original intuitions of Heisenberg and Bohr, but was formalized in the mid-1990s with the birth of the 'relational interpretation of quantum mechanics'.¹⁰⁹ The world of philosophy has reacted to this interpretation in various ways: different schools of thought have framed it in different philosophical terms.

Bas van Fraassen, one of the most brilliant contemporary philosophers, gave it an acute analysis within the framework of his 'constructive empiricism'.¹¹⁰ Michel Bitbol gave it a neo-Kantian reading.¹¹¹ François-Igor Pris read it in the perspective of contextual realism;¹¹² Pierre Livet in terms of the ontology of processes.¹¹³ Mauro Dorato has inserted it into structural realism,¹¹⁴ according to which reality is made up of structures.¹¹⁵ Laura Candiotta has defended the same thesis.¹¹⁶ I do not intend to enter into the debate between different currents of contemporary philosophy. I only add here a few pointers, and tell a personal story.

The discovery that quantities we had thought of as absolute are in fact relative instead is a theme that runs throughout the history of physics. Beyond physics, relational thinking can be found in all the sciences. In biology, the characteristics of living systems are comprehensible in relation to their environment, formed by other living beings. In chemistry, the properties of elements consist of the way in which they interact with other elements. In economics, we speak of

economic relations. In psychology, the individual personality exists within a relational context. In these and many other cases we understand things (organisms, chemicals, psychological life) through their being *in relation to* other things.

In the history of Western philosophy there is a recurrent critique of the notion that 'entities' are the foundation of reality. It can be found in widely different philosophical traditions,¹¹⁷ from the 'everything flows' of Heraclitus to the contemporary metaphysics of relations. Only in the last few years, books of philosophy have come out with titles such as *A Formal Approach to the Metaphysics of Perspectives*,¹¹⁸ and *Viewpoint Relativism: A New Approach to Epistemological Relativism Based on the Concept of Points of View*,¹¹⁹ to name only the most recent examples. In analytic philosophy, structural realism¹²⁰ is based on the idea that relations come before objects:¹²¹ Michel Bitbol has written *From Inside the World: For a Philosophy and a Science of Relations*.¹²² Laura Candiotta and Giacomo Pezzano have published a book with the title *The Philosophy of Relations*¹²³ . . .

But the idea itself is ancient. In the Western tradition we can already find it in the later work of Plato. In *The Sophist*, Plato considers the fact that his atemporal Forms must be able to enter into relation with phenomenal reality to make sense, and ends up putting into the mouth of the central figure in his dialogue, the Stranger from Elea, a famous completely relational (and not very Eleatic) definition of reality: 'I say therefore that what by nature can act on another or suffer even the slightest action from another, however insignificant it is, and even if it happens only once, this alone can be truly real. I therefore propose this definition of being: that it is nothing if not action (*δύναμις*).'¹²⁴ As is not uncommon, someone might be tempted to think that Plato has summed up in a phrase everything that there is to be said on the subject . . .

Even this very incomplete overview is sufficient to show how recurrent the idea is that the world is woven by relations and interactions more than by objects.

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Take an object: this chair that I see in front of me. It is real and stands before me objectively, no doubt about it. But what does it mean exactly – that this whole is an object, an entity, a chair, real?

The notion of a chair is defined by its function: a piece of furniture designed for us to sit on. It presupposes human beings who sit down. It's about the way we conceive of it.

This does not affect the fact that the chair exists right here, objectively. The object is still here, with its obvious physical characteristics of colour, hardness, and so on. But even these characteristics exist only in relation to us. Colour comes from the encounter between the frequencies of light reflected from the surfaces of the chair and the particular receptors in human retinas. It is not about the chair: it is a story between light, retina and reflection. Most other animal species do not see colours as we do. The frequencies themselves emitted by the chair emerge only from the interaction between the dynamics of its atoms and the light that illuminates them.

The chair, still, is an object independent of its colour. If I move it, it moves as a whole. Strictly speaking, not even this is completely true: this chair is made of a seat that rests on a frame, which rises when I pick it up. It is a set, an assemblage of pieces.

What is it that makes this assemblage of pieces a single object, a unit? Effectively, it is little more than the role that this combination of elements plays for us . . .

If we look for the chair in itself, independently of external relations, and especially of its relations to us, we struggle to find it.

There is nothing mysterious about this: the world is not divided into stand-alone entities. It is we who divide it into objects for our convenience. A mountain chain is not divided into individual mountains: it is we who divide it up into parts that strike us as in some way separate. A countless number of our definitions, perhaps all of them, are relational: a mother is a mother because she has a child; a planet is a planet because it orbits a star; a predator is such because it hunts prey; a position in space is there only in relation to something else. Even time exists only as a set of relations.¹²⁵

None of this is new. But physics has long been asked to provide a firm basis on which to place relations: a basic reality underlying and supporting this relational world. Classical physics, with its idea of matter that moves in space, characterized by primary qualities (shape) that come before secondary ones (colour), seemed to be able to play this role: to furnish the primary ingredients of the world that it was possible to think of as existing in their own right, as the basis of the interplay of combinations and relations.

The discovery of the quantum properties of the world is the discovery that physical matter is not capable of fulfilling this role. Fundamental physics does provide an elementary and universal grammar for understanding phenomena, but not a grammar consisting of simple matter in motion, with its own primary properties. The contextuality that permeates the world reaches this elementary grammar. There are no elementary entities that we can describe except in the context of their interaction with something else.

This leaves us without a foothold, no place to stand. If

matter with definite and univocal properties does not constitute the elementary substance of the world, and if the subject of our knowledge is a part of nature, what *is* the world's elementary substance?

To what can we anchor our conception of the world? From where can we begin? What is fundamental?

The history of Western philosophy is to a large extent an attempt to provide an answer to the question as to what is fundamental. It is a search for the point of departure from which everything else follows: matter, God, the spirit, the atoms and the void, Platonic Forms, a priori forms of intuition, the subject, Absolute Spirit, elementary moments of consciousness, phenomena, energy, experience, sensations, language, verifiable propositions, scientific data, falsifiable theories, the existence of the being for whom being matters, hermeneutic circles, structures . . . A long list of candidates, not one of which ever managed to achieve a universal acceptance as ultimate foundation.

The attempt by Mach to take 'sensations' or 'elements' as foundational has inspired scientists and philosophers, but in the end does not seem any more convincing than others. Mach rails against metaphysics, but he effectively produces his own metaphysics – lighter and more flexible, but a metaphysics nonetheless – of elements and functions. A phenomenal realism, or a 'realist empiricism'.¹²⁶

In my own attempts to make sense of quanta for myself, I have wandered among the texts of philosophers in search of a conceptual basis with which to understand the strange picture of the world provided by this incredible theory. In doing so, I have found many fine suggestions and acute criticisms, but nothing wholly convincing.

Until one day I came across a work that left me amazed. I

will end this chapter, which does not have any conclusions, with a light account of this encounter.

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I did not come across it by chance. When speaking about quanta and their relational nature I had frequently met people who asked: Have you read Nāgārjuna?

When I'd heard my umpteenth 'Have you read Nāgārjuna?' I decided to go ahead and read it. Though not widely known in the West, the work in question is hardly an obscure or minor one: it is one of the most important texts of Buddhist philosophy, so it was only due to my personal ignorance of Asian thought (not so uncharacteristic in the West) that I was unaware of it. Its title is one of those never-ending Sanskrit words – *Mūlamadhyamakakārikā* – translated in numerous ways, including *The Fundamental Verses of the Middle Way*. I read it in a translation with commentary by an American analytic philosopher. It has made a profound impression upon me.¹²⁷

Nāgārjuna lived in the second century CE. There have been countless commentaries on his text, which has been overlaid with interpretations and exegesis. The interest of such ancient texts lies partly in the stratification of readings that gives them to us enriched by levels of meaning. What really interests us about ancient texts is not what the author initially intended to say: it is how the work can speak to us now, and what it can suggest today.

The central thesis of Nāgārjuna's book is simply that there is nothing that exists in itself, independently from something else. The resonance with quantum mechanics is immediate. Obviously, Nāgārjuna knew nothing, and could

not have imagined anything, about quanta – that is not the point. The point is that philosophers offer original ways of rethinking the world, and we can employ them if they turn out to be useful. The perspective offered by Nāgārjuna may perhaps make it a little easier to think about the quantum world.

If nothing exists in itself, everything exists only through dependence on something else, in relation to something else. The technical term used by Nāgārjuna to describe the absence of independent existence is ‘emptiness’ (*śūnyatā*): things are ‘empty’ in the sense of having no autonomous existence. They exist thanks to, as a function of, with respect to, in the perspective of, something else.

If I look at a cloudy sky – to take a simplistic example – I can see a castle and a dragon. Does a castle and does a dragon really exist, up there in the sky? Obviously not: the dragon and the castle emerge from the encounter between the shape of the clouds and the sensations and thoughts in my head; in themselves they are empty entities, they do not exist. So far, so easy. But Nāgārjuna also suggests that the clouds, the sky, sensations, thoughts and my own head are equally things that arise from the encounter with other things: they are empty entities.

And myself, looking at a star, do I exist? No, not even I. So who is observing the star? No one, says Nāgārjuna. To see a star is a component of that set of interactions that I conventionally call my ‘self’. ‘What articulates language does not exist. The circle of thoughts does not exist.’¹²⁸ There is no ultimate or mysterious essence to understand that is the true essence of our being. ‘I’ is nothing other than the vast and interconnected set of phenomena that constitute it, each one dependent on something else. Centuries of Western

speculation on the subject, and on the nature of consciousness, vanish like morning mist.

Like much philosophy and much science, Nāgārjuna distinguishes between two levels: conventional, apparent reality with its illusory and perspectival aspects, and ultimate reality. But in this case the distinction takes us in an unexpected direction: the ultimate reality, the essence, is absence, is vacuity. It does not exist.

If every metaphysics seeks a primary substance, an essence on which everything may depend, the point of departure from which everything follows, Nāgārjuna suggests that the ultimate substance, the point of departure . . . does not exist.

There are timid intuitions in a similar direction in Western philosophy. But Nāgārjuna's perspective is radical. Conventional, everyday existence is not negated; on the contrary, it is taken into account in all of its complexity, with its levels and facets. It can be studied, explored, analysed, reduced to more elementary terms. But there is no sense, Nāgārjuna argues, in looking for an ultimate substratum.

The difference from contemporary structural realism, for instance, seems clear: I can imagine Nāgārjuna adding a short chapter to a contemporary edition of his book entitled 'All Structures are Empty'. They exist only when you are thinking about organizing something else. In his terms: 'they are neither precedent to objects; nor not precedent to objects; neither are they both things; nor, ultimately, neither one nor the other thing.'*

The illusoriness of the world, its *samsāra*, is a general theme of Buddhism; to recognize this is to reach *nirvāna*,

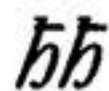
* This is an example of tetralemma, the form of logic used by Nāgārjuna.

liberation and beatitude. For Nāgārjuna, *samsāra* and *nirvāna* are the same thing: both empty of their own existence. Non-existent.

So is emptiness the only reality? Is this, after all, the *ultimate* reality? No, writes Nāgārjuna, in the most vertiginous chapter of his book: every perspective exists only in interdependence with something else, there is never an ultimate reality – and this is the case for his own perspective as well. Even emptiness is devoid of essence: it is conventional. No metaphysics survives. Emptiness is empty.

Nāgārjuna has given us a formidable conceptual tool for thinking about the relationality of quanta: we can think of interdependence without autonomous essence entering the equation. In fact, interdependence – and this is the key argument made by Nāgārjuna, *requires* us to forget all about autonomous essences.

The long search for the ‘ultimate substance’ in physics has passed through matter, molecules, atoms, fields, elementary particles . . . and has been shipwrecked in the relational complexity of quantum field theory and general relativity. Is it possible that a philosopher from ancient India can provide us with a conceptual tool with which to extricate ourselves?



It is always from others that we learn, from those different from ourselves. Despite millennia of uninterrupted dialogue, the East and the West still have something to say to each other. As in the best marriages.

The fascination of Nāgārjuna’s thought goes beyond questions raised by contemporary physics. His perspective has

something dizzying about it. It resonates with the best of much Western philosophy, both classical and recent. With the radical scepticism of Hume, with the unmasking of badly posed questions in Wittgenstein. But it seems to me that Nāgārjuna does not fall into the trap in which so much philosophy is caught, by postulating starting points that invariably turn out to be unconvincing in the long run. He speaks about reality, about its complexity and comprehensibility, but he defends us from the conceptual trap of wanting to find it an ultimate foundation.

His is not metaphysical extravagance: it is sobriety. It recognizes the fact that to inquire about the ultimate foundation of everything is to ask a question that perhaps simply does not make sense.

This does not shut down investigation. On the contrary, it liberates it. Nāgārjuna is not a nihilist negating the reality of the world, and neither is he a sceptic denying that we can know anything about that reality. The world of phenomena is one that we can investigate, gradually improving our understanding of it. We may find general characteristics. But it is a world of interdependence and contingencies, not a world that we should trouble ourselves attempting to derive from an Absolute.

I believe that one of the greatest mistakes made by human beings is to want certainties when trying to understand something. The search for knowledge is not nourished by certainty: it is nourished by a radical absence of certainty. Thanks to the acute awareness of our ignorance, we are open to doubt and can continue to learn and to learn better. This has always been the strength of scientific thinking – thinking born of curiosity, revolt, change. There is no cardinal or final fixed point, philosophical or methodological, with which to anchor the adventure of knowledge.

There are many different interpretations of Nāgārjuna's text. The multiplicity of potential readings is testimony to its vitality and to the capacity of ancient texts to continue to speak to us. What interests us, anew, is not what the prior of a monastery in India was actually thinking nearly two thousand years ago – that is his business (or the business of historians). What interests us is the power of the ideas that emanate today from the lines he left; how these, enriched by generations of commentary, may open up new spaces for thought, intersecting with *our* culture and *our* knowledge. This is the meaning of culture: an endless dialogue that enriches us by feeding on experiences, knowledge and, above all, exchanges.

I am not a philosopher, I am a physicist: a simple mechanic. And this simple mechanic, who deals with quanta, is taught by Nāgārjuna that it is possible to think of the manifestations of objects without having to ask what the object is *in itself*, independent from its manifestations.

But Nāgārjuna's emptiness also nourishes an ethical stance that clears the sky of the endless disquietude: to understand that we do not exist as autonomous entities helps us free ourselves from attachments and suffering. Precisely because of its impermanence, because of the absence of any absolute, the now has meaning and is precious.

For me as a human being, Nāgārjuna teaches the serenity, the lightness and the shining beauty of the world: we are nothing but images of images. Reality, including our selves, is nothing but a thin and fragile veil, beyond which . . . there is nothing.