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The Poetics of Physics

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Professor James Ladyman, Editor
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COVER LETTER

Dear Professor Ladyman,

We have pleasure in submitting to *SHPS* our paper *The Poetics of Physics*. This is a very wide-ranging work which comments on the ontology and epistemology implicit in the recent fundamental developments in the concept of entropy.

We seek to show that "*both the epistemology and the ontology of physics ultimately rests on poetic language*", using the history of the idea of *entropy* as a topical example. In one way this could be taken as a restatement of Michael Polanyi's position that knowledge is personal, and that this is almost always tacit in science praxis (*Personal Knowledge*, Chicago, 1958). But Polanyi's classical thesis is today nearly forgotten, and in any case Polanyi took a philosophical view which ignored the basic poetics of ontology.

Without ignoring the philosophy, we address poetics directly: the Epigraph is a poem in Palikur (an endangered language from the Amazon region), and the final section explores ontological knowledge long predating the Hellenic period in terms of a poem derived from the palaeo-Hebrew on a newly-discovered artefact.

The paper is rather long, but you have confirmed to me (email 2nd May 2021, 13:09) that you would consider it. It is unusually wideranging, touching not only on our recent major results in thermodynamics but also on the history of the idea of entropy starting from Clausius' 1854 paper (in the light of a discussion of the ontics and epistemics of poetics itself) informed by a close discussion of a palaeo-Hebrew text. To be accessible across the various disciplines my text is unavoidably extended, even though I write very tightly.

I should add that because of its interdisciplinary character the paper will also be exceptionally difficult to review: no single Reviewer will claim to be competent on all aspects of it. But in view of this I have sought independent comment as widely as I can, which convinces me that the work is definitely not crazy rubbish! So for the Poetics you could ask the opinion of (for instance) Tudur Hallam (Swansea) or Kate North (Cardiff Met) or Vesna Goldsworthy (Exeter); for the palaeo-Hebrew you could ask the opinion of Rowan Williams (who would encouragingly point you to a language expert); for the philosophy you could ask the opinion of Keith Ward (Oxford, Christchurch). For the philosophy of science I think Michael Berry (Bristol) would also be interested; Tom McLeish (York) certainly would be and so would Philip Ball (former editor of *Nature*, now a journalist).

The science is also developing rather rapidly with three major new papers in 2021 on the *entropic Liouville Theorem* (https://doi.org/10.1016/j.physo.2021.100068), on the *Entropy Production of Galaxies* (https://doi.org/10.3390/universe7090325), and on the sizes of sub-atomic nuclei (in press in *Annalen der Physik*, http://dx.doi.org/10.1002/andp.202100278; preprint: https://doi.org/10.21203/rs.3.rs-112066/v3). You are familiar with thermodynamics, but I think you will find this new work radically unfamiliar in its methods.

We look forward to hearing from you.

Yours sincerely

Chris Jeynes (pp the Authors: Dr.M.C.Parker, Dr.M.Barker & myself)

The Poetics of Physics

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Keywords

Thermodynamics; info-entropy; ontology; epistemology; palaeo-Hebrew; poetry

CRediT

CJ: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Roles/Writing - original draft; Writing - review & editing

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The Poetics of Physics

Abstract

Physics has been thought to truly represent reality since at least Galileo, and the foundations of physics are always established using philosophical ideas. In particular, the elegant naming of physical entities is usually very influential in the acceptance of physical theories. We here demonstrate (using current developments in thermodynamics as an example) that both the epistemology and the ontology of physics ultimately rest on poetic language. What we understand depends essentially on the language we use. We wish to establish our knowledge securely, but strictly speaking this is impossible using only analytic language. Knowledge of the meanings of things must use a natural language designed to express meaning, that is, poetic language. Although the world is really there, and although we can indeed know it truly, this knowledge is never either complete or certain but ultimately must rest on intuition. Reading a recently discovered artefact with a palaeo-Hebrew inscription as from the first century, we demonstrate from it that this ontological understanding long predates the Hellenic period. Poetic language is primary, both logically and temporally.

Epigraph: "*Ku wown biyuke*"

Ku wown biyuke
nikwe ukanuhwan amin madikte arikna inurikyene,
(warukma, kamuw, kayg)
hawwata ukannuhwan umin wis amadgaya inin,
(uhiyakemni akak uwakemni)
in ka ekkepka akisyavrik akiw
ewka awen wownavrik.

Ku wown biyuke
nikwe madikte amadgaya inin,
(parahwokwa, warik, puwiknebdi akak ahavwi)
in ka kinetihwaka nimin akiw,
akak uhiyakemni payak akak uwegewni
mmanawa in kuwis menwe.

Ku wown biyuke
in ke wotbe pahayku lapot sabukwiyebe.
Nikwe hiyeg amedgenevwi inin
awetuvye pukuha
ku samah wowskawni ay amadga inin.

Ku wown biyuke,
unetni adah kiyathaki akak amnihka
unetni adah kayahka akak batekka
wavan, westwa, unetni, uvigyepkawni,
amekenegben gikehnikis
in ka kinetihwakati nimin akiw.

Ku wown biyuke,
— aa, ka aynsima iwit kuwis biyuke,
ka aynsima iwit biyuknene akiw,
kewa pahak waruwbe bekbetepka aritnanyuvwi —
nikwe wahawkrivwiy gikuvimnakis
tinwohawsepka adah avavyekwa
in ke igiskabe ku pariye wis biyukse adah avavyekwa.

If our language is lost
then all our knowledge of things above
(stars, sun, and moon)
and the knowledge of us humans on earth
(our thoughts and our deepest feelings)
will not be properly expressed again
when our language is gone.

If our language is lost
then everything in the world,
(seas and rivers, animals and plants)
may never again be spoken
with our understanding and insights
for these will have already vanished.

If our language is lost
it will be as though a door were closed
to the peoples of the world
and they will never understand
how we lived here on earth.

If our language is lost
our words of respect and love,
our expressions of pain or fondness
our songs, our stories, our talk, our prayers,
the accomplishments of our ancestors
will never be spoken of again.

If our language is lost
— oh, many languages have already been lost
and many more are almost lost,
like mirrors forever shattered —
then our ancestors' voices
will be silenced forever
and a great treasure will be forever lost to us.

after Miguel Leon-Portilla: *Cuando Muere Una Lengua* (1998)

See Supplementary Materials for the audio file of the poet speaking the poem in *Palikur* (and for its *Portuguese* translation), also for the *Náhuatl* original of *Cuando Muere Una Lengua* (and its translation into *English* from the *Spanish*).

1. Meaning as Poetry

In what way can a scientist be like Shakespeare? Tom McLeish[1] recently quoted Shakespeare's 100th Sonnet ("*Where art thou Muse …*") saying, "*it has never been easy to speak with clarity about moments of imaginative conception*" ([ref.1] p.7), and we will also quote Dante Alighieri speaking of his Muse (§4.4). McLeish eloquently discusses a variety of cases showing how scientists *imagine* reality before they are able to establish their new theories, and how these imaginative (creative) approaches are actually central because of "*new patterns and connections that they offer for specific creative demands*" ([ref.1] p.331). Seeing new things requires imagination!

Almost a century ago Owen Barfield[2] famously spoke of "*poetic diction*", that is: "*the language of poetic compositions*" ([ref.2 III:5):

> When we start explaining the language of famous scientists as examples of '*poetic diction*' … [it is no] waste of time [if it helps anyone to be convinced] how essentially parochial is the fashionable distinction between Poetry and Science as modes of experience
>
> Owen Barfield, *Poetic Diction* VIII:6 (1928)

seeking to establish, like McLeish, that epistemologically there is little distinction between artists and scientists: they are all similar in how they come to know new things.

If I say (with Parker & Jeynes, 2019[3]), "*information has calculable entropy and obeys physical laws*", what do I mean? And how can you understand me? Barfield says that "*the poet's relation to terms is that of maker*" (VIII:4[*]); *information* and *entropy* here are terms referring to certain aspects of physical reality and it is clear that the terms are made by the physicists: are they (as both Barfield and McLeish outrageously seem to say) in some sense thereby poets?

We will here give an affirmative answer, and try to elaborate helpfully. We will explore the specific case of how we address the scientific concepts of *entropy* and its close companion *information*, which together represent difficult ideas in a currently very active (and contentious) field of research. We point out that the very close relation between information and entropy is now well established: recently this relation has been articulated in mathematical detail as a "new" concept of *info-entropy* within the overall theory of Quantitative Geometrical Thermodynamics (QGT) [ref.3].

Using these test cases, we seek to show how the initial development of scientific ideas depends in the first instance on an intuitive understanding that relies on intrinsically poetic language. Before a scientific concept can be understood it must be articulated, and language is essential to articulate scientific ideas: we cannot *know* anything without being able to *say* what it is we know (without language we have inchoate *feeling*, not *knowledge*). Science is effected by humans acting humanly – that is, using language! Stones don't know things: people do. Our knowledge of the world is necessarily based ultimately on intuition, and the articulation of intuited knowledge is the business of poets. Before it is anything else, natural language is poetic.

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[*] Barfield says of this dictum: "The *use* of them [the terms] is left to the Logician, who, in his endeavour to keep them steady and thus fit them to his laws, is continually seeking to *reduce* their meaning. I say seeking to do so, because logic is essentially a compromise. He could only evolve a language, whose propositions would *really* obey the laws of thought by eliminating meaning altogether. But he compromises before this zero-point is reached" (italics original). This is entirely consistent with our view, *mutatis mutandis.*

Saying that *knowledge is necessarily mediated by words* sounds like the *linguistic determinism* famously proposed by Benjamin Lee Whorf [4]. We do not take this position, but rather that of the "*relay results*" advocated by McLeish [ref.1] (who relies on Jacques Hadamard's 1945 *The Psychology of Invention in the Mathematical Field*):

> ... James Clerk Maxwell would urge mathematicians to formulate their thinking in 'words without the aid of symbols', not because he would sympathize with the lingualists, but because he knew the creative force of communicating ideas Tom McLeish *The Poetry and Music of Science* p.243 (2019)

We note that McLeish explicitly considers the parallels between scientific creativity and the (wordless) creativity of painters and musicians: that is, there does exist a "knowledge" that is ***not*** mediated by words, but we consider this wider view of knowledge as outside our present scope. Michael Polanyi also considered such knowledge, which he called "***tacit***" (see Part II – "*The Tacit Component*" – of his *Personal Knowledge*, 1958[5]). We here only consider scientific knowledge from the point where it becomes crystallised in words:

> The formulation of the fruitful question, posed in the right way, constitutes the great imaginative act in science Tom McLeish *The Poetry and Music of Science* p.10 (2019)

We are also distinguishing sharply between "*information*" (which is physical) and "*knowledge*" (which is mental). *I know* precisely because *I am informed*. Stones incorporate *information* from which geologists can glean *knowledge*.

The thesis of this paper is that where physics must use *analytic* language, metaphysics must involve irreducibly *poetic* language. Language is intrinsically metaphorical: all our words have concrete referents but none of them is *merely* concrete, they all come with a cluster of connotations. A "*metaphor*" (after the ancient Greek *μεταφέρειν*, to transfer) can be thought to *translate* (or transfer) between these connotations, and this idea of "*translation*" is essential to our thesis. We will show (using the particular case of *entropy*) that the narrative of physics is only established in the context of a metanarrative (here metaphysics) which constructs the meanings of the ideas to be used in a natural language as unambiguous as possible. This metaphysical step is usually carefully ignored by philosophers of science: Nicholas Maxwell's "*aim-oriented empiricism*"[6] approach (predicated on the *metaphysical priority* of unified theories) is a welcome exception. But *standard empiricism* glosses over the idealistic foundations of how we *interpret* observations.

Note that natural language is always ultimately poetic, especially where new meanings are being created. Meaning is always *negotiated* between speakers and poets find new and resonant ways of doing this: Martin Edwardes[7] has shown how this *negotiated meaning* must be central to ontology. When scientists establish new concepts they must "negotiate the meaning" of the terms they use for these new concepts. We show here how this works in the case of *entropy* (and *info-entropy*).

Understanding physical concepts therefore always involves an intuitive leap in meaning from the concrete to the metaphysical, which we could also arguably (and nearly equivalently) call the *spiritual*. The very word *spirit* exemplifies this intuitive leap. Today the English word *spirit* has a range of metaphysical connotations, but in the original Latin it also carried the concrete meaning *wind* (which English word has an Anglo-Saxon etymology). So for example, there is a Greek record of Jesus' saying (John 3:8):

Original text[8] (<70 CE[9]†):	το πνευμα οπου θελει πνει ... που υπαγει ουτως εστιν πας ο γεγεννημενος εκ του πνευματος
transl. Jerome (c.400 CE):	Spiritus ubi vult spirat ... sic est omnis qui natus est ex spiritu
transl. Tyndale (1526)[10]:	The wynde bloweth where he listeth [where it wills] ... so is every man that is boren of the sprete [born of the spirit]

Note that cognates of the same word are used in both Greek and Latin (πνευμα, πνει, πνευματος / *spiritus, spirat, spiritu*) where three different words are needed in English (*wind, blow, spirit*). Translation of nuance is irreducibly creative: both Jerome and Tyndale had poets' ears.

Returning to the original question, what is *entropy* and what is *information*? These are ontological questions (the ontology of the "*physical law*" in the original question is well-trodden ground[11] and out of our present scope). How do we understand entropy and its relationship to information? This is an epistemological one. To answer these questions we have to translate from the concrete to the general; that is, from specific observations to an articulation of a coherent theory. We will proceed to explore these issues, taking as examples the meanings of "*information*" and "*entropy*". Our thesis is that moving from the concrete observation of physical reality to the general articulation of a physical theory we cannot avoid brushing with the spiritual (in the sense explained above, which in this context would usually be called "metaphysical").

Barfield already knew a century ago that there is no clear line between *poetry* and *prose*: in reality these are undefinable categories, strictly speaking. But there is a clear distinction between poetic language and the analytic language that scientists must use. The poet relishes ambiguity, which is fundamental in language and essential to poetry. But the point of analytical language is to reduce the inherent ambiguity of language as far as possible.

To be explicit here (since we will systematically contrast *poetic* and *analytic* language), poets have a free hand to use words any way they choose to invoke meaning to the hearers, making as full use as they like of the range of connotation (the *ambiguity*) of the words used. If the poet is successful then the hearer perceives meaning in the poem. On the other hand, scientists must *analyse* the ideas they wish to develop into components that are specified and combined as unambiguously as possible. But where do the scientists' ideas come from in the first place?

The analytical narrative must be encased in a metanarrative (as we will show); moreover, poetic perception cannot be spoken of analytically. The early Wittgenstein famously said, "*That whereof one cannot speak, thereof one must be silent*", but the later Wittgenstein changed his mind, saying instead, "*In most cases, the meaning of a word is its use*". In our terms, he switched from believing that analytic language was sufficient, to recognising that poetic language was ontologically indispensable. Something similar can be said of Richard Rorty: in 1982 he famously said (citing William James) that truth is "*a compliment paid to sentences that seem to be paying their way*"[12]; but in 2000 he says: "*it was a mistake on my part to go from criticism of attempts to define truth as accurate representation of the intrinsic nature of reality to a denial that true statements get things right*"[13]. Of course, we argue here that it is a logical mistake to try to "*define truth*".

Our epigraph touches both ontic and epistemic issues. It is written (after a poem in *Náhuatl*, an autochthonous Mexican language) in *Palikur*, a northern Arawak language spoken by less than four thousand people living in the Brazilian state of Amapá and in French Guiana. There is a Palikur-

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† We give dates for the *New Testament* texts (conveniently but anachronistically reproduced in a miniscule Greek script with word spacing) as authoritatively discussed in 1976 by John Robinson.

Portuguese dictionary[14] and the language displays *ways of knowing* that differ markedly from modern European ones[15]. The way we think – our very identity – is inextricable from our *language* (and the *Náhuatl* and the *Palikur* poems both express how horrible its loss would be: "*The culture, the people, everything would disappear forever*"[16]). What we *know* is inexpressible without language. Benjamin Lee Whorf (1941) drew attention to the converse of this: "*… people act about situation in ways which are like the ways they talk about them*" [ref.4], but this only serves to underline our point. If we cannot say it we cannot know it: this is true for all aspects of reality.

But first we must consider "reality" itself. The paper is constructed as an essay on ontics and epistemics: what things *are* and how we *know* them. We start by exploring the *thinginess of things* (§2), that is, the rational structure both of reality itself and of our knowledge of it. We then, separately, summarise the surprising development of the ideas of *entropy* and *information* (§3) as a specific example of how meaning is negotiated in physics. We underline (§4) this *negotiating of meaning* in the development of knowledge as being an exercise that necessarily involves poetics. The whole essay revolves around the recognition of *language* as the primary and essential medium of knowledge, and we give an example of this (§5) that uses a detailed analysis of an artefact that is demonstrably a mnemonic of a very sophisticated view of *knowledge* long predating the Hellenic schools of philosophy. We gather the threads of the argument together (§6) and finally conclude (§7).

2. The Thinginess of Things

Michael Frayn has memorably spoken of the "*thinginess of things*"[17‡], that is, the sure ontological grasp that reality appears to have on us. Things *are*! This has long been resonant with the poets: for example, Wallace Stevens spoke specifically of "*A new knowledge of reality*"[18].

Thing is a very ancient word with a surprisingly wide range of connotation (including *parliament*), and which is thought to be related to the Indo-European root of the Latin word *tempus*, time. Of course, material things only exist – can only exist – in time: Frank Wilczek[19] (ch.6, p.159) points out that this underlies Augustine of Hippo's elegant proof that the Christian doctrine of Creation entailed the creation of *time* along with matter. For, Augustine said, we only know time by the movement of things (he fixed their ontology by calling them "creatures" – that is, things made by the Creator); therefore, if there are no things then neither can there be time:

> procul dubio non est mundus factus in tempore, sed cum tempore ... nullum autem posset esse praeteritum, quia nulla erat creatura, cuius mutabilibus motibus ageretur
>
> verily the world was made with time, and not in time ... no time passed before the world, because no creature was made by whose course it might pass. But it was made with time, if motion be time's condition — Augustine, *City of God* XI:6, 426 CE[20]

There is also a similar statement in a lengthy and acute discussion in Book XI of the *Confessions*. Thus Augustine anticipates the conclusion of Hawking & Penrose's *Gravitational Singularity Theorem*[21] (that *time* had a beginning) by a millennium and a half.

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‡ "*Thingification*" is an interesting word whose first usage the Oxford English Dictionary (OED) attests in 1935; the OED lists *thinghood* as used by A.N.Whitehead, but sadly does not list the (better) synonym *thinginess* (philosophers might speak instead of "*reification*", a Latinist neologism of the mid-19th century). The OED also attests all of *thingly* (adjective), *thingy* (both as a noun and an adjective), *thingness*, and *thingliness* (respectively 1450, 1787, 1891, 1840, 1662).

All physicists operate on the assumption (not usually explicitly acknowledged) that the thinginess of the phænomena they investigate is ontologically secure: that is, the world is real.[§] Philosophically this ontological security derives from the assertion of Creation by the monotheist religions, even if most physicists today assume it tacitly merely as a pragmatic precondition. Interestingly, Gerry Schroeder[22] has shown *both* that the Hebrew Creation story successfully resists scientific criticism, *and* that its interpretation is as subtle and elusive as any poetic text.

It is important to realise[**] that the thinginess of things is *ontologically axiomatic*, as Frayn effectively acknowledges in a long discussion. Our ultimate epistemological reliance on personal guarantee is documented by Richard Bauckham (2006)[23] in the context specifically of historical events: ultimately, we know things only through *eyewitness testimony*:

> The testimony of Holocaust survivors is the modern context in which we most readily recognise that authentic testimony from participants is completely indispensable to acquiring real understanding of historical events, at least events of such exceptionality. Bauckham, 2006 §18 (p.499)

We can of course subject *testimony* to the standard critical tests, but in the end we usually have to decide whether we trust the witness or not. In the end we have to choose what to believe. Note that "*personal guarantee*" also underlies the peer review system, which cannot operate without good faith. Thus, *testimony* also underlies the epistemology of scientific knowledge.

Michael Polanyi in his "*Personal Knowledge*" (1958) [ref.5] also insists that ultimately we have only *personal* guarantees of whatever knowledge we think we possess: strictly speaking, *objective knowledge* is an oxymoron:

> ... the intuition of rationality in nature [must] be acknowledged as a justifiable and indeed essential part of scientific theory. That is why scientific theory ... [can be] represented as a mere economical description of facts ... or as a working hypothesis ... [but these are] interpretations that all deliberately overlook the rational core of science.
>
> ... great theories are rarely *simple* in the ordinary sense of the term. Both quantum mechanics and relativity are very difficult to understand; it takes only a few minutes to memorize the facts accounted for by relativity, but years of study may not suffice to master the theory and see these facts in its context.
>
> ... We understand the meaning of the term 'simple' only by recalling the meaning of the terms 'rational' or 'reasonable' or 'such that we ought to assent to it', which the term 'simple' was supposed to replace. The term 'simplicity' functions then merely as a disguise for another meaning than its own. It is used for smuggling an essential quality into our appreciation of a scientific theory which a mistaken conception of ***objectivity*** forbids us to acknowledge. Polanyi, 1958, 1:4

How do we know that nature is rational (and therefore amenable to scientific description)? We intuit it. Prior to our rationalisations is our belief that rationalisations exist. And in speaking of *rationality* here, Polanyi is also referring to the primacy over common sense scientists commonly give to idealistic thought (we have already mentioned Maxwell's "*aim-oriented empiricism*" [ref.6]). On his first page Polanyi asks, *What is the true lesson of the Copernican revolution?* And he answers:

> Copernicus gave preference to man's delight in abstract theory, at the price of rejecting the evidence of our senses, which present us with the irresistible fact of the sun, the moon, and the stars rising daily in the east to travel across the sky to their setting in the west. Polanyi, 1958 (*op.cit.*), 1:1

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§ "*Real*" is another nice word whose extensive cluster of connotations includes *royalty* – well-known today by the many followers of premier-ranked *Real Madrid*.

** punning deliberately on *real*!

The fact may be psychologically "*irresistible*"; nevertheless, Polanyi points out that behaving rationally we systematically do resist it. We may "intuit" that the sun goes round the earth; but at a deeper level we intuit that the relation of sun to earth is lawful, and analytically we recognise that the simplest expression of the law has the earth going round the sun. We intuit the existence of the rationality that underpins this lawfulness. It is the business of poets to articulate intuition.

Of course, Polanyi is aware of the logical necessity of this attitude to rationality, which becomes clear (as he explains) when Kurt Gödel's Incompleteness Theorem (1931)[24] is understood. Quoting S.C.Kleene's *Introduction to Metamathematics* (1952), Polanyi says,

> Rules have been stated to formalise the object theory, but now we must understand without rules how those rules work. An intuitive mathematics is necessary even to define the formal mathematics.
>
> Polanyi, 1958 (*op.cit.*), 8:8

Gödel's achievement was to demonstrate by construction that his formula (which we can express in words as "*this sentence is undecidable*") was not meaningless. His demonstration was rather involved, but indicates the processes of mind required to establish this cornerstone of epistemology. We display its flavour with this brief extract from his Introduction (*K* is the set of "Gödel numbers" *q* representing *unprovable* formulas):

> Die Analogie dieses Schlusses mit der Antinomie Richard springt in die Augen; auch mit dem „Lügner" besteht eine nahe Verwandtschaft, denn der unentscheidbare Satz [$R(q)$; q] besagt ja, daß q zu K gehört, [das heißt] nach (1), daß [$R(q)$; q] nicht beweisbar ist. Wir haben also einen Satz vor uns, der seine eigene Unbeweisbarkeit behauptet.
>
> 13) Man beachte, daß „[$R(q)$; q]" ... bloß eine metamathematische Beschreibung des unentscheidbaren Satzes ist.
>
> The analogy between this result and Richard's antinomy leaps to the eye; there is also a close relationship with the "Liar", since the undecidable proposition [$R(q)$; q] states precisely that q belongs to K, that is according to Eq.1, [$R(q)$; q] is not provable. We are therefore confronted with a proposition that asserts its own unprovability.
>
> (footnote #13) Note that "[$R(q)$; q]" ... is merely a metamathematical description of the undecidable proposition.
>
> Gödel, 1931 (op.cit.)

Richard's paradox was stated in 1905, but the Liar Paradox is ascribed to Epidemides of Crete, alluded to by St. Paul (Titus 1:12, 57 CE [ref.9]), and investigated at length among others by the 14th century John Buridan (who conditioned Galileo's theory of *impetus*)[25].

It is well-known that Gödel later became fascinated by Anselm's comparable *Ontological Argument* for the existence of God (*Proslogion*, 1078 CE[26]). Anselm asserted that the idea, "*aliquid quo maius nihil cogitare potest*" ("*that than which no greater can be thought*") was not unthinkable, and therefore God (than which no greater can be thought) must exist in fact. Starting from this premise of "*thinkability*", Anselm actually gave a proof that in its self-referencing form anticipated Gödel's proof by a millennium:

> Et certe id quo maius cogitare nequit, non potest esse in solo intellectu. Si enim vel in solo intellectu est, potest cogitare esse et in re, est in solo intellectu: id ipsum quo maius cogitare non potest, est quo maius cogitare potest. Sed certe hoc esse non potest.
>
> And surely *that-than-which-a-greater-cannot-be-thought* cannot exist in the mind alone. For if it exists solely in the mind even, it can be thought to exist in reality also, which is greater. If then *that-than-which-a-greater-cannot-be-thought* exists in the mind alone, this *that-than-which-a-greater-***cannot***-be-thought* is *that-than-which-a-greater-***can***-be-thought*. But this is obviously impossible.
>
> Anselm, 1078 (*op.cit.*) II

The elegance of Anselm's Latin is noticeable. And one can hear an attenuated echo of this ontological argument in Descartes' famous dictum "*cogito ergo sum*", which George Berkeley modified to "*esse est percipi*" deliberately to contrast the idealism of the scholastic nominalists with the new materialist schools. Anselm goes on to comment on the relation between believing (ontics) and understanding (epistemics) that is central to our present work:

> Gratias tibi, bene dominum, gratias tibi, quia quod prius credidi te donante, iam sic intelligo te illuminante, ut si te esse nolim credere, non possim non intelligere.
>
> I give thanks, good Lord, I give thanks to you, since what I believed before through your free gift I now so understand through your illumination, that [even] if I did not want to *believe* that you existed, I should nevertheless be unable not to *understand* it. Anselm, 1078 (*op.cit.*) IV

This is reminiscent of Augustine's dictum "*nisi crediteris non intelligetis*" ("if you do not believe you will not understand": *City of God,* XII:17; quoting a version of Isaiah 7:9). But Anselm has recognised how the increase of knowledge works – first we *see*, then we *understand* – which is equally true for painters, for poets, and for physicists. First one grasps the *idea*, then one works out the details. Just because the devil is in the detail does not mean that the initial illumination is dispensible. Just because many ideas turn out to be incoherent does not mean that the fruitful ideas do not originate with illumination. One is reminded of Eric Dodds' comment (1951, in his Preface): "*time and the critics can be trusted to deal with the guesses; the illumination remains*"[27].

We are not here saying that we reliably grasp things by intuition – everyone knows this is not the case! To test the reliability of our ideas we have to do science in the usual way. But where does the idea itself come from? Its origin is the "*illumination*" discussed by Anselm, or the "*leap of faith*" (properly, the "*leap by faith*") discussed by Søren Kierkegaard (and heavily debated ever since: earlier we called this an "*intuitive leap*"). We *discern* truth: nevertheless, uncertainty cannot be eliminated.

Both Gödel's and Anselm's sentences are self-referencing, and have logical properties entirely due to this recursiveness. Gödel's sentence is proved "*not meaningless*" (and therefore true) by construction, but because of its wider scope Anselm's sentence has resisted such construction.

Gödel's proof was a revolution, not only in its overturning of the expectation of the mathematicians that arithmetic could be proved *both* consistent *and* complete (Gödel cites the 1925 edition of Russell & Whitehead's monumental work *Principia Mathematica*, and also David Hilbert's work in arithmetic), but also in its entirely novel style of proof, relying explicitly on a *meta*mathematical argument. It is interesting not only that Anselm anticipated Gödel, but also that he understood the logical status of his argument, which he did not present analytically but poetically (as a prayer). Ultimately, ontic knowledge is only, and can only be, intuited. How else can one understand Paul of Tarsus writing about God, who:

> καλουντος τα μη οντα ως οντα (Romans 4:17 [ref.8], 57 CE [ref.9])
>
> calleth thoſe things which be not as though they were (*transl:* Tyndale, 1526 [ref.10])

We have a complementary view of the necessarily intuitive nature of the knowledge of thinginess, expressed in a different context by Thomas Piketty (2019)[28]. In a section titled "*On the Complementarity of Natural Language and Mathematical Language*", Picketty says:

> This book will rely primarily on natural language ... There is no substitute for natural language when it comes to expressing social identities or defining political ideologies. ... Those who believe that we will one day be able to rely on a mathematical formula, algorithm, or econometric model to determine the "socially optimal" level of inequality are destined to be disappointed. ... I do not contend that "truth" is found only in numbers or certainty only in "facts". Picketty, 2019, Ch.1

To be clear: we are distinguishing between the *natural* language we use every day, the *analytical* language required for science, and the *poetic* language (which may look like "natural" language) needed to express deep meanings.

Picketty encloses "facts" in quotes since these are always contentious in economics: one person's verity is always another's heresy, and Picketty authoritatively displays the *ideological* nature of such "facts". But it turns out that physics is also ideological in a similar way and for similar reasons. Of course, this is not entirely unexpected: this present essay could be thought of as merely a footnote to Thomas Kuhn's seminal book of a generation ago (*The Structure of Scientific Revolutions*, 1962). We proceed to explore this ideology specifically in relation to the development of ideas of entropy since the mid-19th century.

3. Entropy and Information

3.1 Early work on the concept of Entropy

Entropy is a slippery concept. Edwin Jaynes (1965)[29] says about it, in a paper explaining some fundamental aspects of the (19th century) treatments of John Willard Gibbs and Ludwig Boltzmann:

> It is interesting that, although this field [entropy] has long been regarded as one of the most puzzling and controversial parts of physics, the difficulties have not been mathematical. ... It is the enormous *conceptual* difficulty of this field which has retarded progress for so long.
>
> Jaynes, 1965 (emphasis original)

The Oxford English Dictionary (OED) is very helpful. Rudolf Clausius introduced the term *entropy* in 1865[30] specifically as a Hellenistic neologism: from *ἐν* + *τροπή* (transformation; literally 'turning': all the connotations of *trope* are also present in English). The OED comments:

> Clausius assumed that (German) *Energie* literally meant 'work content' (*Werkinhalt*) and devised the term *Entropie* as a corresponding designation for the 'transformation content' (*Verwandlungsinhalt*) of a system. Oxford English Dictionary, 3rd Edition (September 2018)

And then, in sense 1a ("*Physics & Chemistry*"), the OED elaborates:

> Entropy was first defined by the German physicist Rudolf Clausius (1822–88). Scottish physicists Peter Guthrie Tait (1831–1901) and James Clerk Maxwell (1831–79) were the first to interpret entropy as *a measure of the unavailability of energy for work*.
>
> The modern mathematical definition of entropy, in terms of the possible microstates ... of a thermodynamic system, first appears in the work of Austrian physicist Ludwig Boltzmann (1844-1906), who viewed entropy as *a measure of the disorder of a system*.
>
> [Sense 3 "*Statistics and Information Theory*")] ... mathematician Claude Shannon (1916-2001) coined the term in the context of information theory (see sense 3b)
>
> Oxford English Dictionary, 3rd Edition (September 2018)

The OED gives a variety of definitions, three related to scientific concepts. (We will show below that these do not exhaust the meanings assigned to the term.) This is not merely a philological variety, but a real scientific discrepancy that has led to much confusion. It is still not entirely clear whether the multiple definitions do actually refer consistently to a coherent idea. But the confusion has certainly resulted in error. Indeed, as Jaynes noted (in 1992[31], near the end of his life) regarding his variational approach to provide an underlying principle to entropy *"…the long confusion about order and disorder (which still clutters up our textbooks) is replaced by a remarkable simplicity and generality*".

The very logical status of the Second Law of Thermodynamics has long been debated, as hinted at above. Is it a fundamental Law? Or is it a consequence of the other Laws, which are all time-reversible (except for the CP-violation by K-mesons discovered by Cronin & Fitch)? Either way, consistency is a problem. How can time reversibility be consistent with time irreversibility (see below on the "Arrow of Time", §3.6)? Clausius first clearly stated a version of the Second Law in 1854[32]:

> es kann nie Wärme aus einem kälteren in einen wärmeren Körper übergehen, wenn nicht gleichzeitig eine andere damit zusammenhängende Aenderung eintritt.
>
> heat can never pass from a colder to a warmer body without some other change, connected therewith, occurring at the same time. Clausius, 1854

In the same 1854 paper, Clausius also recognised (before he had introduced the term) that entropy remains unchanged for reversible cyclic processes ("*umkehrbaren Kreisprocesse*"), calling the identity $\int dQ/T = 0$ the "second law of the mechanical theory of heat" ("*des zweiten Hauptsatzes der mechanischen Wärmetheorie*"). Of course, the "first law" was $Q = U + A{\cdot}W$, where Q is the total quantity of heat ("*die ganze Wärmemenge*"), U is how much heat is in the system before work is done on it, W is the external work ("*die äuſsere Arbeit*"), and A is the factor converting work to heat ("*das Wärmeaequivalent für die Einheit der Arbeit*", literally: "the heat equivalent for the unit of work"). It is instructive to see how Clausius reasons here:

> Bei dieser Bestimmungsweise kann man den Satz von der Aequivalenz von Wärme und Arbeit, welcher nur einen speciellen Fall der allgemeinen Beziehung zwischen lebendiger Kraft und mechanischer Arbeit bildet, kurz so aussprechen:
>
> > **Es läſst sich Arbeit in Wärme und umgekehrt Wärme in Arbeit verwandeln, wobei stets die Gröſse der einen der der anderen proportional ist.**
>
> … Betrachten wir nun die bei einer Zustandsänderung gethane innere und äuſsere Arbeit zusammen, so können sich beide, wenn sie von entgegengesetzten Vorzeichen sind, theilweise gegenseitig aufheben, und dem Reste muſs dann die gleichzeitig eintretende Aenderung der Wärmequantität aequivalent seyn. Für die Rechnung aber kommt es auf dasselbe hinaus, wenn man für jede von beiden einzeln eine aequivalente Wärmeänderung annimmt.
>
> Sey daher Q die ganze Wärmemenge, welche man einem Körper, während er auf einem bestimmten Wege aus einem Zustande in einen andern übergeht, mittheilen müſs, (wobei eine entzogene Wärmemenge als mitgetheilte negative Wärmemenge gerechnet wird), so zerlegen wir diese in drei Theile, von denen der erste die Vermehrung der wirklich in dem Körper vorhandenen Wärme, der zweite die zu innerer und der dritte die zu äuſserer Arbeit verbrauchte Wärme begreift.
>
> Von dem ersten Theile gilt dasselbe, was schon vom zweiten gesagt ist, daſs er von der Art, wie die Veränderung stattgefunden hat, unabhängig ist, und wir können daher beide Theile zusammen durch eine Function U darstellen, von der wir, auch wenn wir sie sonst noch nicht näher kennen, wenigstens soviel im Voraus wissen, daſs sie durch den Anfangs- und Endzustand des Körpers vollkommen bestimmt ist.
>
> Der dritte Theil dagegen, das Aequivalent der äuſseren Arbeit, kann, wie diese selbst, erst dann bestimmt werden, wenn der ganze Weg der Veränderungen gegeben ist. Nennen wir die äuſsere Arbeit W, und das Wärmeaequivalent für die Einheit der Arbeit A, so ist der Werth des dritten Theiles $A{\cdot}W$, und wir erhalten daher als Ausdruck des ersten Hauptsatzes folgende Gleichung: (I) $Q = U + A{\cdot}W$
>
> With this means of determination, one can now concisely express the relation between the equivalence of heat and work (which is only a special case of the general relationship between active power and mechanical work) by the following saying:
>
> > **Work can be turned into heat and *vice versa* heat can be turned into work, so that the magnitude of the one is always proportional to the other.**
>
> … Let us now consider, in the event of a change of state, the internal and external work together. These both, taken together, can partially compensate each other if they are of opposite signs. Then the remainder must be equivalent to the change of the quantity of heat that occurs at the same time [i.e.

> during the change of state event]. For the calculation however, it comes back to the same thing, if one assumes an equivalent change in heat from the two separate entities [i.e., for each of internal work and external work separately, one takes the heat equivalent].
>
> Let Q be the entire quantity of heat that must be imparted to a body, while going on a certain path from one state to another (where heat removed is counted as a negative quantity of heat imparted) [this is in the context of the Carnot cycle]. This can be broken into three parts, of which the first is the increase of heat actually present in the body, the second is the heat used for internal work and the third the heat used for external work.
>
> Of the first part one can say the same as has already been said about the second part: that it is independent of the way that the change of state happened. We can therefore combine both parts together into a function U, for which we know in advance (regardless of how little knowledge we otherwise have) that it is completely (sufficiently) defined by the initial and final states of the body.
>
> On the other hand, the third part, i.e. the equivalent of the external work, can only be calculated when the whole path of change is given. We call the external work W, and the heat equivalent for the unit of work A, so that the value of this third part is the product $A{\cdot}W$, and we come into view of the resulting first law in the following equation: (I) $Q = U + A{\cdot}W$
>
> Clausius, 1854 (*op.cit.*; emphasis original)

It is plain that the equation, $Q = U + A{\cdot}W$, derives its meaning from the previous discussion, which is in a German that is both syntactically and semantically complex: it defies a literal translation and it is hard to translate into a comprehensible English. Clausius is trying to describe the effect of *entropy* without knowing its explicit existence or name (he only coined the term in his 1865 paper [ref.30]), hence the apparent confusion and inarticulacy of this complex text of 1854. We leave the linguistic analysis as an exercise for the interested reader, but we conclude that Clausius is carefully constructing ("*negotiating*") meanings for the terms he wishes to manipulate mathematically in just the way that Barfield says is characteristic of poets.

This is a rather clear example of metaphysical priority in a physical argument. We will discuss the logical properties of metanarratives later: here we see Clausius using a natural language (replete with metaphor and its consequent ambiguity), and intending to restrict the unavoidable ambiguity as much as possible. It is only by using natural language that we can say anything at all, but then if we care about the meanings we are constructing we have to also address the formal poetics. Of course, usually this step is tacit, but we are here drawing attention to it.

Physicists tend to think that they can manipulate the behaviour of *phænomena* symbolically, but in fact they only symbolically manipulate the *ideas* they have constructed of those behaviours. Whence arise the ideas? And what relation (both ontic and epistemic) has the idea to the phænomenon?

3.2 Entropy and Statistical Mechanics

All students of thermodynamics start today with the model of the ideal Carnot cycle, which establishes the ideas of "waste heat" and "maximum thermodynamic efficiency". Clausius depended on the Carnot cycle to model his idea of "entropy" as the accessible useful work available in some quantity of heat – in his time the steam engine powered the world: is it any wonder that (as we shall see) the ideal gas laws should be the natural exemplar of heat engines? Actually, Carnot's seminal treatment relied on the false idea of *caloric*: it was Clausius who found the correct interpretation we still use (see Paul Sen, 2021[33]). It was also Clausius who recognised that the *change* in the internal energy U of the system is path-independent and therefore that U is what we would now call a "function of state" (for a close discussion of this see Jennifer Coopersmith, 2015[34]).

It is by considering the ideal gas as a model for heat engines that today's students learn the basics of statistical mechanics, first developed with great brilliance by the mid-nineteenth century giants of physics: Gibbs, Boltzmann and Maxwell. Ludwig Boltzmann is remembered by his eponymous constant *k*, and by the formula engraved on his tombstone:

$$S = k \log W \qquad \text{(Eq.1)}$$

which in this form is due to Max Planck. The symbol "*S*" (denoting *entropy*) originated with Clausius, possibly indicating the integral ("*Summe*": $\int dQ/T$) he introduced to define the "second law". In modern terms *S* has the unit Joules per Kelvin (energy/temperature), where the idea of "*absolute temperature*" was clear to Clausius who already knew in 1854 that 0 °C = 273 K (accepting the 1848 value of William Thomson – later Lord Kelvin). "*W*" (supposedly from "*Wahrscheinlichkeit*", probability) denotes the number of different states the system can have. From this formula Boltzmann could derive the ideal gas law in what is now a textbook treatment.

It is now also well-known that this "simple" treatment ignores or obscures a number of severe difficulties. The usual definition makes entropy an *extensive* quantity, yet it is known that this is an approximation that is appropriate only in certain circumstances:

> Entropy is just as much, and just as little, extensive in classical statistics as in quantum statistics ... entropy stands strongly contrasted to energy. Jaynes, 1992

Strictly speaking, entropy is an *intensive* quantity, as Jaynes observes in a penetrating discussion in the same place of the so-called *Gibbs Paradox*:

> [Gibbs] had perceived that, when two systems interact, *only the entropy of the whole is meaningful*. Today we would say that the interaction induces correlations in their states which makes the entropy of the whole less than the sum of entropies of the parts; and it is the entropy of the whole that contains full thermodynamic information. This reminds us of Gibbs' famous remark, made in a supposedly (but perhaps not really) different context: "*The whole is simpler than the sum of its parts*." How could Gibbs have perceived this long before the days of quantum theory? Jaynes, 1992 (emphases original)

Jaynes earlier had made an astonishing statement of the *subjectivity* of the concept of entropy in his acute comparison of the Gibbs and Boltzmann formulations:

> ... not only in the well-known statistical sense that it measures the extent of human ignorance as to the microstate [but also] *[e]ven at the purely phenomenological level, entropy is an anthropomorphic concept*. For it is a property, not of the physical system, but of the particular experiments you or I choose to perform on it. Jaynes, 1965 [ref.29] (emphasis original)

The point here is that the result of the entropy calculation depends on how the Partition Function of the system is specified, that is, which particular measurements are being contemplated. The Partition Function describes how phase space (which enumerates all of the *microstates*) is specified. Then the observables are specified by the *macroscopic parameters*, which can hopefully be calculated from the thermodynamics. Roger Penrose puts this quite sharply:

> ... we can ... appreciate ... [that] Boltzmann's formula ... put forward in 1875 ... represented an enormous advance on what had gone before ... There are, nevertheless, still certain aspects of vagueness in this definition, associated, primarily, with the notion of what is to be meant by a "macroscopic parameter". Penrose, 2010, §1.4 [35]

Carlo Rovelli made essentially the same point very recently when he argues that "*we are blind to many variables [that are] at the heart of Boltzmann's theory*", adding:

> Thermodynamics ... is a description of *these* variables of the system: those through which we assume we are able to interact with the system Rovelli, 2017 (ch.10, n.4; *emphasis original*) [36]

However, it was Max Planck who in 1900 first recognised "Boltzmann's constant" *per se* as fundamental to entropy in the seminal paper[37] in which he explains black body radiation in terms of quantised resonators; and where he gives the quantisation constant, h, in units of action with the value $6.55.10^{-34}$ J.s (this is correct to almost 1%: today's value is $h = 6.63.10^{-34}$ J.s).

His argument involves a calculation of the *entropy* of the system of resonators, and therefore also involves Boltzmann's relation (which he gives correctly, that is, up to a constant factor and using the natural logarithm: "$S = k \ln W + constant$"). He obtains the values of both eponymous constants (the "Planck" and the "Boltzmann" constants, h & k, which he calls "universal" or "natural" constants) by considering the accurate measurements of what we now call *Wien's displacement constant*, $b = 2.94$ mm.K, that had then recently appeared (today's value is $b = 2.90$ mm.K): he obtains $k = 1.346.10^{-23}$ J/K (today's value is $1.381.10^{-23}$ J/K).

3.3 Information

The first transatlantic "telegraph" cable was laid in 1858 but only operated for three weeks. A lasting transatlantic connection was established in 1866. In addition to its technical triumph, this was commercially very valuable (and expensive) technology, and the search for efficiency naturally attracted great scientific attention. The first message was transmitted (by Morse code, in 1858) at 10 minutes per word. The second (1866) cable already operated almost two orders of magnitude faster, at 8 words per minute; but the transmission speed (that is, the *bandwidth*) was necessarily slow because of frequency dispersion in the cable: this was already understood in principle by William Thompson (later Lord Kelvin) who published his analysis in 1854 and was closely involved with the enterprise.

However, although practical development (telegraphy with time- and frequency-division multiplexing, telephony, radio) was very rapid, little advance was made on what we would now call *informatics* until the 1920s, when it became clear that "*bandwidth limitation sets a fundamental limit to the possible information transfer rate of a system*" (quoting Lars Lundheim's useful review[38]). And the very idea of *bandwidth* depends on the understanding of electrical '*band pass*' *filters*, which were not patented until 1917.

The additional problem of *signal-to-noise* dominated telecommunications science as soon as more reliable long distance signalling was allowed by usable amplifiers (i.e. valves, exploiting the vacuum tube technology which had originally been developed for the incandescent light bulb). But in the 1920s there was still no standard scientific understanding of noise: Norbert Wiener's work on stochastic noise (Brownian motion) was published between 1920 and 1924, and Harry Nyquist's mathematical model of thermal noise was only published in 1928. The vacuum tube amplifier had been introduced around 1910, but the high gains obtainable by cascading amplifiers had to wait until the feedback principle was patented in 1928. And then noise became important to control, being a limiting factor to transmission systems: "*by the 1930s signal-to-noise ratio had become a common term among communications engineers*" (Lundheim, *op.cit.*).

It is this century of prior telecommunications history that set the scene for Claude Shannon's breakthrough paper of 1948[39] in which he re-used the term *entropy* to give a measure of "what rate information is produced" in a communication channel. In this work he showed quantitatively how the maximum bit-rate depended both on the noise in the channel and on its bandwidth, and he also established that completely error-free information exchange was possible, as long as the data rate in the channel was below a certain value (the "channel capacity").

> When one compares the generality and power of explanation of Shannon's [1948] paper "*A Mathematical Theory of Communication*" to alternative theories at the time, one can hardly disagree with J.R.Pierce [1973] who states that it "came as a bomb".
>
> Lundheim, 2002 (*op.cit*.)

Shannon (1948) used the term *entropy* as referring to "quantities of the form $H = -\sum p_i \log p_i$" which "*play a central role in information theory as measures of information, choice and uncertainty*" specifically because it had the same form as that "*defined in certain formulations of statistical mechanics*" (citing Richard C.Tolman's magisterial *Principles of Statistical Mechanics*, 1936), and it is now known as the "information entropy", or the "Shannon entropy". Shannon used the symbol *H* to invoke "*the* H *in Boltzmann's famous* H *theorem*".

Responding to Shannon, Leon Brillouin considered "information" in 1953 as negative entropy: *negentropy* [40]; and Jaynes' seminal work of 1957 [41] amplified Shannon's observations on probability distributions saying, "*the development of information theory has been felt by many people to be of great significance for statistical mechanics, although the exact way in which it should be applied has remained obscure*"; but then adding:

> In this connection it is essential to note the following. The mere fact that the same mathematical expression $-\sum p_i \log p_i$ occurs both in statistical mechanics and in information theory does not in itself establish any connection between these fields. This can be done only by finding new viewpoints from which thermodynamic entropy and information-theory entropy appear as the same *concept*.
>
> Jaynes, 1957 (emphasis original)

Jaynes went on to establish the congruence of the ideas of thermodynamic and information-theoretic entropies, demonstrating that using a probability distribution that *maximizes the entropy* (subject to certain constraints) justifies making inferences from that distribution. Following Jaynes, the powerful "Maximum Entropy" ("MaxEnt") methods are now very widely used across a large variety of technical disciplines.

Rolf Landauer famously drew specific attention to the entropy cost of computation, originally in 1961 [42], insisting that *computation is physical*. Although many of the steps in a computation can be carried out reversibly, information *erasure* is necessarily irreversible, and carries an inescapable entropy cost, as was emphasised by Charles Bennett:

> Landauer's principle, while perhaps obvious in retrospect, makes it clear that information processing and acquisition have no intrinsic, irreducible thermodynamic cost whereas the seemingly humble act of information destruction does have a cost, exactly sufficient to save the Second Law from [Maxwell's] Demon. Bennett, 2003 [43]

Today, as Parker & Jeynes [ref.3] have pointed out, citing significant recent work in network theory: the entropic treatment of information is standard in the analysis of the efficiency of communications networks in the presence of noise [44]; also, applying Landauer's Principle to a computation involves the transfer of information and therefore also results in a rise in entropy [45]. They go on to show that information and entropy should be considered (*contra* Brillouin) not as *opposites*, but as *complementary* (that is, orthogonal in complex Minkowski 4-space). And indeed, they use the Shannon information entropy explicitly to discuss the stability of fullerenes: "*So for example, for C_{60} … we can calculate an entropy … using the Shannon fragmentation metric*." [46]

3.4 The Entropy of Black Holes

The Bekenstein-Hawking equation for S_{BH}, the entropy of black holes, is due to seminal work in 1973 by Jacob Bekenstein [47] where he showed that the entropy of the black hole is proportional to its surface area (that is, the area A of its event horizon). Stephen Hawking gave an argument in 1976[48] for the value of the constant of proportionality, leading to the celebrated equation, $S_{BH} = \frac{1}{4}Akc^3/(G\hbar)$, where as usual k, $\hbar$, c and G are respectively Boltzmann's constant, the reduced Planck constant, the speed of light and the gravitational constant.

Again in this formula, as for Planck's treatment of the black body radiation, it is the ratio h/k that is significant, and for Planck this was directly fixed by the Wien displacement constant b, with units of K.s (Planck calls this unit "*grad·sec*"); clearly related by the speed of light c, such that $\hbar/kc \sim b$.

Bekenstein explicitly uses the Shannon information entropy in his derivation, specifically in the sense of the "*inaccessibility of information about* [the black hole's] *internal configuration*", thereby also implicitly employing Brillouin's concept of "negentropy":

> [here] we attempt a unification of black-hole physics with thermodynamics. In Sec. II we point out a number of analogies between black-hole physics and thermodynamics, all of which bring out the parallelism between black-hole area and entropy. In Sec. III, after a short review of elements of the theory of information, we discuss some features of black-hole physics from the point of view of information theory. We take the area of a black hole as a measure of its entropy – entropy in the sense of inaccessibility of information about its internal configuration. Bekenstein, 1973

It was in 1974 that "Hawking radiation" was discovered[49], confirming Bekenstein's 1973 suggestion that black holes have a "temperature" ; as indeed does any object having a finite entropy. Hawking demonstrated that in fact the black hole behaves as though its event horizon is a (typically very cold) black body with a temperature inversely proportional to the black hole mass (for the central supermassive black hole of the Milky Way this works out as 15 fK). But at the event horizon of a black hole there is no matter that is not infalling: clearly, the idea of "temperature" is here used in a very different sense from normal temperatures, which always refer to a statistical (macroscopic) property of some sort of particle ensemble.

In 2019, Parker & Jeynes [ref.3] showed how the Bekenstein-Hawking expression for the black hole entropy can be used to determine the virial mass of the Milky Way galaxy from the known mass of the supermassive black hole at the galactic centre. The galactic virial mass (which includes both the observed stellar mass and the inferred "dark matter" mass) is the galactic mass that can be inferred by the motion of its stars. Their derivation of the virial mass was a simple application of their recasting of the *maximum entropy* condition into an entropic Lagrangian/Hamiltonian formulation of equilibrium thermodynamics (the so-called *Quantitative Geometrical Thermodynamics*, QGT), in which the *double-helix* and the *double logarithmic spiral* are proved to be holomorphic structures conforming to maximum entropy geometries. The double logarithmic spiral is a good zeroth order model for spiral galaxies and QGT offers an explanation for the MaxEnt *stability* of a spiral galaxy without needing "dark matter", but of course galaxies are necessarily structures that are far from equilibrium, and the calculation of galactic virial mass has a number of as yet unresolved associated problems.

However, recently Parker & Jeynes[50] have shown in the framework of QGT how the Bekenstein-Hawking expression itself is a consequence of Liouville's Theorem, expressed in entropic terms. (Arno Keppens[51] also independently derives the B-H expression by considering the consequences of the underpinning of Bousso's[52] "holographic principle" by the quantisation of space-time.)

Black holes are extremely simple objects which are specified by only four parameters: mass, charge, angular momentum and the "Planck length" (Frank Wilczek [ref.19] – ch.3, p.73 – omits the scale of "*elementary particles*" when he characterises them as those having only mass, charge and spin). It is because black holes are so simply specified that they are so definitely known to be ontologically simple: their property of being maximum entropy (MaxEnt) objects is also related to their ontological simplicity. However, even though they are very simple MaxEnt objects, nevertheless they are not in thermodynamic equilibrium. They necessarily accrete mass. As yet, although it has been extended by Parker & Jeynes[53] to idealised spiral galaxies to yield an expression for the *entropy production* (a conserved quantity), the QGT formalism has not yet been systematically extended to express the evolution of MaxEnt objects in time. But it is already clear that such an extension would be natural to the formalism since an expression for "entropic force" is available (Parker & Jeynes 2019 [ref.3] eq.23).

3.5 Geometric Entropy: Holography and Entanglement

The holographic properties of black holes have long been recognised, together with the non-local consequences. So Raphael Bousso [ref.52] said, in a review originating in developments in quantum gravity:

> The holographic principle … implies that the number of fundamental degrees of freedom is related to the area of surfaces in spacetime. Typically, this number is drastically smaller than the field theory estimate. Thus the holographic principle calls into question not only the fundamental status of field theory but the very notion of locality. … Quantum gravity has imprinted few traces on physics below the Planck energy. Among them, the information content of spacetime may well be the most profound. Bousso, 2002 (*op.cit.*)

What is striking about the treatment of Parker & Jeynes (2019 [ref.3]) is the *non-local* properties of the entropy, so that the spiral galaxies have their shape (on this account) as a consequence of the holomorphism of the double logarithmic spiral, which is a primary *geometric* property, even if it can also be shown in standard treatments to emerge from the kinematics. They say:

> we have shown that the [double logarithmic spiral] structure of the … Milky Way … is consistent with a holomorphic representation in geometric algebra. In particular, we have shown that the [calculated] galactic shape, aspect ratio, and structural stability (which are all highly constrained by the algebra) are consistent with observation; and we have also shown that the total galactic mass is also consistent with observation. Note that this is a simplified ("zeroth order") analytical approximation to reality: … the dynamics driving the galactic evolution [are neglected … but] this treatment gives the proper weight to the effect of the black hole entropy Parker & Jeynes, 2019 (*op.cit.*)

Parker & Jeynes [ref.46] prove that the stability of Buckminsterfullerene (C_{60}) is a *geometrical entropy* property fundamentally related to its representation as a holomorphic object. They say that the stability is:

> [a property] of the thermodynamics of the system: [which is] a significant methodological advance since a detailed treatment of the energetics may be avoidable. … The spherical C_{60} fullerene molecule therefore represents a least exertion or Maximum Entropy (most likely) topology … For C_{60} the double-spiral trajectories have been proved holomorphic and maximum entropy in an exact Euler-Lagrange analytical treatment (given the approximation to a true spherical geometry). Parker & Jeynes, 2020 (*op.cit.*)

Parker & Jeynes [ref.50] also demonstrate directly that the holographic principle itself is a consequence of the *entropic* Liouville Theorem:

> The geometric entropy of both the sphere and the double-helix are clearly holographic in nature, since they are proportional to the surface areas of enclosed volumes. …
>
> … consideration of the geometric entropy of systems ranging … from the molecular … through to [cosmic] scales yields a common holographic interpretation … The holographic principle itself … is a consequence of the holomorphism … of the objects considered.
>
> The close relationship between quantum mechanics … and statistical mechanics … is well known … However, using geometric entropy and the entropic version of Liouville's Theorem … we have shown not only how the

> entropy of a MaxEnt system is holographic in nature, but also that there exists an associated entropic version of the uncertainty principle, based on the Boltzmann constant as the appropriate entropic counterpart to the Planck constant.
> Parker & Jeynes, 2021 (*op.cit.*)

Further work has shown that the holographic principle is also effective at sub-atomic scales: Parker *et al*.[54] express the nuclear sizes of the helium isotopes (^{4}He, ^{6}He, ^{8}He) and the self-conjugate $A = 4n$ nuclei (^{4}He, ^{8}Be, ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, ^{36}Ar, ^{40}Ca) in terms of a single parameter, the "*holographic wavelength*" associated with the entropic geometry: all of these calculated values being entirely consistent with measurement.

In our present context, the point about holography is precisely that *each part represents the whole*, that is, it carries the implication of non-locality. It is of course well-known that "individual" electrons in an atom, or "individual" nucleons in a nucleus are strictly indistinguishable in a proper quantum treatment: this implies that in a holographic system all the "individual entities" are actually somehow mutually entangled.

Entanglement at the microscopic scale is currently well understood. But the galactic scale also appears to us to have some properties which seem similar. It is clear that our idealised spiral galaxy, expressed as a (holomorphic) double-logarithmic spiral, is treated by the QGT formalism as an object whose entropy is given holographically, just like the entropy of its central supermassive black hole. But then, should the galaxy not also be considered as *entangled*, just as are quantum objects like atoms and atomic nuclei? After all, *entanglement* represents another way to speak of *non-local influence*, and what could be more non-local than the symmetry of well-formed spiral galaxies, which are common in the Universe?

3.6 The Arrow of Time, and Teleology

Time asymmetry is a problem because all the laws of physics we know are apparently time-symmetrical, apart from the Second Law of Thermodynamics (and the CP properties of the K-meson). Whence then the Second Law? Is it independent of the other laws? In any case, how can it be consistent with the other laws considering that it is *not* time-symmetrical but almost all the other laws we know of *are*?

One approach to this adopted recently by widely disparate authors is to deny that the arrow of time is real: that is, time does not have a beginning. Carlo Rovelli claims that the reality is that the arrow of time is a matter of perspective: "*Time is Ignorance*" (ref.[35]), justifying this by a discussion of Boltzmann's statistical mechanics apparatus (a discussion amplified in detail with considerable subtlety by John Earman[55]). Roger Penrose claims to have found a way of extending Time back beyond the Big Bang singularity with his detailed suggestion of *Conformal Cyclic Cosmology* (ref.[33]). Ilya Prigogine claims that *Time Precedes Existence*[56]. All of these eminent scientists recognise that they here venture into metaphysics[††], but we dissent from their conclusions essentially on physical grounds. Of course, none of them could have taken the recent developments in thermodynamics into account.

Robert Bishop[57] discusses the problem of the arrow of time in the nonequilibrium statistical mechanics of Prigogine's "Brussels–Austin Group"[58]: he considers "*the observed direction of time to be a basic physical phenomenon due to the dynamics of physical systems*" and continues:

[††] the *New Scientist* (28th October 2020) notes that "Rovelli's bestsellers saw him dubbed *the poet of physics*"

> One claimed virtue [of this approach] … is the ability … to provide time-asymmetry. … Why then do we not observe [entropy decreasing]? To answer this question … [and by] translating their conception of entropy into information-theoretic language [they] showed that their formulation of the second law requires infinite information for specifying the initial states of a singular distribution evolving in the negative [time] direction, but only finite information for specifying the initial states for evolution in the positive [time] direction.
>
> This would render the initial conditions for systems to approach equilibrium along the negative *t*-axis physically unrealizable … Since singular probability distributions are supposedly operationally unrealizable, they argue it is physically impossible for unstable systems to evolve to equilibrium in the negative [time] direction. Hence, their version of the second law acts as a selection rule for initial states.
>
> This argument is supposed to show why anti-thermodynamic behavior in the real world is impossible … Nevertheless, the argument is problematic. The most fundamental difficulty is that it conflates epistemic concepts (e.g., information, empirical accessibility of states) with ontic concepts (e.g., actual states and behaviors of systems). Bishop, 2004 (*op.cit*.)

Here again we see *entropy* (the subject of the Second Law) intricately tied up with *information*, a relation we have already explored above. We also have an explicit statement of how even the best minds can experience "fundamental" epistemological and ontological difficulties in this whole subject.

In this context we wish to point out the teleology apparently implicit in the *Principle of Least Action*. Photons "decide" which path to take on the basis of this Principle. That is, they can be represented as doing a variational calculation over all possible paths, and choosing the *least action* path. Of course, we know that such anthropomorphising language cannot be used properly of photons, but what precisely is it that constrains them to take the paths they do? They behave as though they had a purpose, and the consequence of the Second Law is that the universe behaves as though its purpose is to maximise entropy. But we exorcised teleology from science when we abandoned Aristotle in the 17th century.

It turns out that there is an entropic counterpart to the *Principle of Least Action*: the *Principle of Least Exertion*. Parker & Jeynes [ref.46] explain:

> [Parker & Jeynes, 2019 [ref.3]] have shown that the *principle of least action* has the entropic analogue of a *principle of least exertion*: where "action" is the path integral of the kinematic Lagrangian, "exertion" is the path integral of the entropic Lagrangian – which still satisfies the various canonical conjugate-pairing relationships. Roughly speaking, in the energy domain where the Hamiltonian represents the total energy of a system (that is, the sum of potential and kinetic terms), the Lagrangian represents an energy balance (the difference of potential and kinetic terms). The entropic Hamiltonian-Lagrangian treatment emerges from a consideration of information as the orthogonal complement to entropy Parker & Jeynes, 2020 (*op.cit*.)

It seems that a proper consideration of *entropy* (implying the arrow of time) is intimately linked up on the one hand with the physical quantity *exertion* and the variational *principle of least exertion*, and on the other hand with holographic properties of objects which can be at any scale, from sub-atomic to cosmic (entropy being essentially scale-less, as is witnessed by the logarithm in Eq.1). And these holographic properties are essentially non-local, giving those wedded to mechanical cause-and-effect modes of thought the impression of teleology.

Michael Stöltzner[59] has investigated the teleological aspects of the *Principle of Least Action* (the **PLA**), showing that the logical empiricists (such as Moritz Schlick, Hans Hahn and Philipp Frank) ignored the PLA on account of these apparently teleological aspects even though Max Planck and David Hilbert emphasised it (and Jennifer Coopersmith has recently underlined its fundamental nature in an elegantly deep and wide-ranging treatment[60]). Planck considered "*the PLA as formal embodiment of his convergent realist methodology*", and Hilbert "*took the PLA as the key concept* *in his axiomatizations of physical theories*"; serving "*one of the main goals of the axiomatic method*", that is, "*deepening the foundations*." Stöltzner points out that for Planck and Hilbert and their schools, the PLA did not have the theological connotations ascribed to it by Maupertuis (for example). He says:

> Both its staunchest advocates and those remaining silent about the PLA shared the conviction that final causation, material or organismic teleology, and analogies with human behavior had to be kept out of physics. Stöltzner, 2003 (*op.cit.*)

Just so! Aristotelian teleology was simply a baleful error that proved far too influential. We could however note here that Stöltzner cautions: "When it comes to philosophy, the German word *Zweckmäßigkeit* is notoriously difficult to translate. *Teleology*, *finality*, and *purposiveness* capture only part of it". The question of what precisely is the intended meaning of the words we use obtrudes persistently, even in a technical or scientific context. Stöltzner continues:

> Moreover, none of the protagonists of the debate under investigation considered the PLA as an instance of backward causation. The history of physical teleology might alternatively suggest a relationship between the PLA and the problem of determinism. ... neither PLA-advocates nor logical empiricists contemplated any relation between the PLA and the second law of thermodynamics [except Boltzmann]. Rather, they explicitly restricted the validity of the PLA to reversible phenomena regardless of their views on causality. Stöltzner, 2003 (*op.cit.*)

It seems to us that we need to revisit this debate since the heroes of physics at the beginning of the 20th century knew nothing of *exertion* and the *Principle of Least Exertion* (**PLE**) that Parker discovered (ref.[3]), and which is demonstrated both complementary to the PLA and also emerging from the QGT formalism. He has shown that this QGT formalism is general, that is, it is also valid for non-equilibrium (irreversible) systems, like spiral galaxies.

The new (QGT) treatment of *info-entropy* is entirely consistent with standard ideas of causality: the treatment of *information* presupposes this. However, we suspect that apparent causality paradoxes observed in the past associated with the PLA should instead be viewed as *entanglement* effects of the non-locality. This may have very wide-ranging ramifications, including putting David Bohm's "pilot wave" proposal[61] in a new light, as Parker *et al*. comment:

> It is worth pointing out that Bohm's recognition of a "quantum-mechanical" potential U(x) exerting a "quantum-mechanical" force "*analogous to, but not identical with*" the conventional strong force on a nucleon ([Bohm, 1952 ref.61] his Eq.8), can now be understood to be a prescient anticipation of our *entropic force*, familiar from our previous discussion of galactic geometry ([Parker & Jeynes, 2019: ref.3] their Eq.23). Parker *et al*. (2021 [ref.54])

Bohm's [ref.61] proposal is considered by Rovelli to violate his *Hypothesis 2* (completion) of his *Relational Quantum Mechanics*[62]. However, neither Bohm nor Rovelli take account of Parker's *Principle of Least Exertion* [ref.3] in any way, even though both of them give significant weight to the (physical) quantity *Information* in their different treatments. But Parker has shown that a physical system cannot be treated completely unless its *info-entropy* is also considered.

Alastair Rae[63] has observed: "*If, as a result of the modern work on irreversible processes, we were to be led to a fundamental physics that took as its central theme the idea that time really does flow in one direction, I at least would certainly welcome it*." Parker's info-entropy formalism presupposes the arrow of time, since it treats the Second Law of Thermodynamics as axiomatic. And since the fundamental nature of the variational Principles is uncontroversial (and since the info-entropy formalism naturally generates the PLE as the entropic isomorph of the PLA), it seems that Rae's desire is satisfied.

4. Knowledge of Meaning

4.1 The problem of Definition

Things are what they are: ultimately they are ineffable (except to poets): they are hard to speak of, and they *cannot* be defined. We can only define the ideas we have of things, not the things themselves. But to speak coherently about things we *must* define the ideas we have of them. We cannot speak of any thing without having some more or less clear idea of what it is. It should be obvious that although the ontology of the thing (its thinginess) and its epistemology (how we know it) are intrinsically separate ideas, yet in any specific case the two must be inextricably bound together. We cannot know anything about the thinginess of the thing without also knowing how we know. This is true despite the fact that this knowledge is almost invariably implicit (or "tacit").

The problem then is the propensity we have of confusing our idea of the thing with the thing itself. We think that because we have a satisfactory idea of the thing, we know the thing in itself. If I ask, *What is entropy?* you may answer, with early Clausius: *It is a measure of how much work is available in a quantity of heat*; or with later Clausius: *It is a closed line integral of the change in heat of a body at the absolute temperature of the body at the time of the change*; or with Boltzmann (as later interpreted by Planck): $S = k \ln W$; or with Shannon $\{S = k \sum p_i \ln p_i\}$; or with Parker & Jeynes: *the maximum entropy of a holomorphic body is a holographic property of its geometry*.

All of these answers are correct in their own terms, but an observer could be forgiven for thinking that they do not all describe the same thing: the "thermodynamics" used by Parker and co-workers might be almost unrecognisable by Clausius and Boltzmann. Is it the same? Is Parker's "entropy" the same as Clausius' "entropy"? Both use a recognisably similar mathematical apparatus, but does this establish identity? We have already quoted Edwin Jaynes (1957) on this: "*The mere fact that the same mathematical expression occurs both in statistical mechanics and in information theory does not in itself establish any connection between these fields*." But Jaynes went on to show that in fact statistical mechanics (Boltzmann's achievement) and information theory (Shannon's achievement) really are both truly thermodynamics. And Parker's entropy is too, since his achievement is firmly built on Jaynes'. This conclusion is clearly a real semantic development in word usage, as well as being a startling development of the mathematical apparatus.

The very word *thing* itself was originally used of immaterial things, as we have seen. In fact, the first group of meanings listed in the Oxford English Dictionary are entirely of immaterial things ("*A meeting, or the matter or business considered by it, and derived senses*"): only the second group of meanings (§§8-17: "*An entity of any kind … in the most general sense, in fact or in idea*") concerns material things, and then only in a secondary way. It is only in sense §11 that the word is used to denote explicitly *material objects*. It is clear that in standard English usage a property of a thing is also itself a (different) thing. The curious fact appears to be that *things* are no less thingy for not being concrete. In which case one can hardly be surprised if things turn out to be hard to tie down. Indeed, in 1991 Landauer wrote a popular paper "*Information is Physical*" [64] (on the thermodynamics of information erasure) which precisely emphasised the *thinginess* of a quantity that most people assumed was too abstract to be a thing!

Recently, rather similar and highly relevant observations have emerged in a different context. Mari *et al*. (2013)[65] have drawn a careful philosophical distinction between *being a quantity*, and *being measurable*. They point out that this distinction is an *ontological* one, and moreover, that "*measurement is primarily an epistemic process*"! Underlying this treatment is the recognition that "*knowledge is constructed by humans*": that is, as we have already insisted above, ultimately knowledge is *personal*. This position is explored in more detail by Maul *et al*. (2016)[66] who deprecate "*the appearance of rigor and objectivity* [achieved] *by reducing abstract ideas to observables*". Knowledge, being constructed by humans, is necessarily and intrinsically ideological: these authors we cite are metrologists who include a member of the JCGM (*Joint Committee for Guides in Metrology*), a committee of the BIPM (*Bureau International des Poids et Mesures*: International Bureau of Weights & Measures).

4.2 Metaphysics and metanarratives

In the proof of the Incompleteness Theorem Gödel himself makes parallel use of two strands of argument, the mathematical and the metamathematical. He says [ref.24]:

> Der im System PM unentscheidbare Satz wurde also durch metamathematische Überlegungen doch entschieden.
>
> So the proposition which is undecidable in the PM system yet turns out to be decidable by metamathematical considerations — Gödel, 1931 (*op.cit.*)

where "PM" here refers to Russell & Whitehead's axiomatisation of arithmetic in *Principia Mathematica* (2nd ed. 1925). Note that Whitehead himself said of this work (1929[67], p.8), "*even in mathematics the statement of the ultimate logical principles is beset with difficulties, as yet insuperable*". Whitehead goes on to comment acerbically that "*peccant premises*" in incorrect philosophical arguments are notoriously hard to locate.

Aristotle's book τὰ Φυσικά (*The Physics*) has a title perhaps most helpfully translated *Natural Philosophy*. Similarly, the title of his τὰ μετὰ τὰ Φυσικά (*The Metaphysics*) might be *Beyond Nature*. The one deals (largely) with material things, the other mainly with the immaterial. There is a widespread prejudice today that the immaterial has little or no real existence. The way Gödel proved his Theorem, by the formal use of a metamathematical argument, demonstrates that such an assumption is without foundation. It seems that strict materialism is irrational.

Be that as it may, it seems logically inescapable that every narrative necessarily has its metanarrative without which it can make no sense. And this is true also in pure physics, as we have seen by showing how the metaphysics is implicit in the history of the idea of *entropy*.

4.3 Ambiguity and Coherence

We have seen Clausius carefully constructing unambiguous meanings for the terms he wishes to manipulate mathematically – using linguistic means. Strictly speaking, this is specifying the physics by means of a metaphysical discourse. Philosophers of science have tended to obscure this step as much as they can, but it is ***explicit*** even in the proof of the Incompleteness Theorem, as we have seen. Even to do fundamental mathematics we are forced to recruit the help of metamathematical methods: is it then surprising that at the fundamentals of physics also lurk metaphysical methods?

But rational speech is not limited to analytical speech. Poetic speech derives any power it may have from its internal coherence: and coherence is a property of rationality. The epistemology of physics rests on the foundation of socially verified personal testimony, which is a form of poetic speech.

Form and the knowledge of form are both prior to all scientific knowledge. Prior to all rationalisation is the knowledge of the possibility of rationalisations. Rationality itself is a poetic, not an analytic property. E.R.Dodds was writing early (1951) and can be forgiven his idea of "*irrational intuition*" ([ref.27], p.217 *passim*), which in our terms is quite mistaken.

Three millennia ago the Psalmist underlined the rationality of the (necessarily intuited) knowledge of God, insisting that the epitome of rationality – that is, the regularity of the heavens – was specifically a pointer to the knowledge of God, saying:

> The heauens declare the glorie of God ... the law of the LORD is perfite [perfect], conuerting the ſoule ... the ſtatutes of the LORD are right, and reioice the heart Ps.19:1,7,8 (Geneva, 1560[68])
>
> οι ουρανοι διηγουνται δοξαν θεου ... ο νομος του κυριου αμωμος επιστρεφων ψυχας ... τα δικαιωματα κυριου ευθεια ευφραινοντα καρδιαν Ps.18:2,8, 9 (LXX [69‡‡])

Some four centuries after the Psalmist, the prophet Jeremiah took up the same idea, insisting that the *rationality* of God was an earnest of the *dependability* of God:

> Beholde, the daies come, ſaith ye LORD, that I wil mak a <u>newe couenant</u> with the houſe of Iſraél, and with the houſe of Iudáh ... Thus ſaith the LORD, which giueth the ſunne for a light to the day, and the courſes of ye moone and of the ſtarres for a light to the night ... If theſe ordinances departe out of my ſight, ſaith the LORD, then ſhall the ſeed of Iſraél ceaſe from being a nation before me, for euer. Jeremiah 31:31,35,36 (Geneva, 1560)
>
> ιδου ημεραι ερχονται φησιν κυριος και διαθησομαι τω οικω ισραηλ και τω οικω ιουδα <u>διαθηκην καινην</u> ... ουτως ειπεν κυριος ο δους τον ηλιον εις φως της ημερας σεληνην και αστερας εις φως της νυκτος ... εαν παυσωνται οι νομοι ουτοι απο προσωπου μου φησιν κυριος και το γενος ισραηλ παυσεται γενεσθαι εθνος κατα προσωπον μου πασας τας ημερας Jeremiah 38:31,36,37 (LXX)

Whence the laws of physics on whose nature all physicists depend? Today the tendency would be to say something equivalent to: never mind the ontic antics, shut up and calculate! But it seems that much that we are interested in is non-calculable, that is, it "*inherently is non-algorithmic and, therefore, cannot be surrogated and simulated in a Turing machine*" (Rubin & Crucifix, 2021[70]).

Until quite recently, the standard answer to the ontological question "*whence natural law?*" would have been to point to Jeremiah's καινη διαθηκη (*new testament*) which underlies European civilisation in the last two millennia. And Jeremiah asserts that this "new testament" is a covenant guaranteed by the testimony of the very heavens: "*if ever these laws* (νομοι) *depart from before my face* (προσωπου) …"!

These ancient poets were *poets*, not scientists: even Jeremiah predated the peak of Hellenic science with Thales being his younger contemporary. The later Alexandrian scholars responsible for the Greek text we display could not help interpreting the Hebrew, but even their Greek is a complex text

‡‡ We give the ancient (*koine*) Greek text rendering the ancient Hebrew because the Hebrew original (with its vocalisation remembered separately) was not a *text* as we now understand it: the Masoretic text (essentially the "pointed" Hebrew text of Samuel ben Jacob) was only completed in modern times (1010 CE: the "*Leningrad Codex*"). The unpointed (original) Hebrew text is an *abjad*, that is, a very highly compressed mnemonic (consonantal) text: the vowels are preserved by the oral tradition (known as the *Masorah*). The "*Masoretic text*" ("MT") encodes this vocalisation into the text itself by a sophisticated "pointing" system. The Greek translation of the Hebrew (the *Septuagint*, "LXX") was started in the 3rd century BCE by the Jewish scholars in Alexandria at the request of the Pharaoh (Ptolemy II), and probably essentially finished by the 2nd century BCE. Note that the chapter numbering varies between the MT and LXX for *Jeremiah* and *Psalms*. The LXX is itself a canonical text for Christians since the *New Testament* quotes it *verbatim* in many places.

We use the English of the *Geneva* translation (1560) since this was widely reprinted and used up to and beyond the Restoration of Charles II (1660), remaining very influential through the substantial dependence on it of the King James Version (1611) which became the dominant text in English until the mid-20th century. The *New Testament* of both *Geneva* and KJV are heavily dependent on Tyndale's 1526 *New Testament*.

with multiple ambiguities; ambiguity which is clearly intended by the poet, and which is enhanced by the *coherence* of the text.

We have said that entropy is scale-less: how then does the little *cohere* with the large? Parker & Jeynes (2019 [ref.3]) correctly calculate an energy of 1.2×10^{-15} J required to transform a DNA molecule to a different form: they also correctly calculate the energy-equivalent galactic mass of the Milky Way as 2.3×10^{59} J, an energy 74 orders of magnitude larger. Parker *et al*. (2021 [ref.52]) also correctly calculate nuclear sizes: the atomic nucleus is some nine orders of magnitude smaller than the DNA molecule treated previously. But exactly the same (thermodynamic) methods are in use, as expected since the Laws of Thermodynamics are expected to apply at all scales.

4.4 Meaning in Poetry

Lo giorno se n'andava, e l'aere bruno
toglieva li animai che sono in terra
da le fatiche loro; e io sol uno

m'apparecchiava a sostener la guerra
si` del cammino e si de la pietate,
che ritrarra la mente che non erra.

O muse, o alto ingegno, or m'aiutate;
o mente che scrivesti cio ch'io vidi,
qui si parra la tua nobilitate.

The day was dying, and the darkening air
Brought all the working world of living things
To rest. I, only, sweated to prepare
For war, the way ahead, the grind that brings

The battler to hot tears for each yard gained:
To bitter tears, and memories more real
Than what was real and which is thus retained
Unblunted, edged with even sharper steel.

My Muse, my schooled and proven gift, help me:
It's now or never. Fortify my mind
With the vivifying skills of poetry,
For what I saw needs art of a great kind.
I saw great things. Give them nobility.

Dante Alighieri, *Divina Commedia*, 1320 (*transl.* Clive James, 2013); Canto II

We quote Dante's masterpiece because, at the start of Canto II, the poet is thinking about how to say what he wants, and how hard it is. Also because the form of the work is untranslatable, as is most poetry (and the idea of "*translation*" is essential to this thesis). We have chosen Clive James' translation[71] because he asserts that Dante's *terza rima* simply does not work in English: instead he uses quatrains, sometimes expanded, as here. And also because Dante deliberately makes use of a variety of poetic means to convey his meaning. James says:

> Dante was one of the most educated men of his time even in the conventional sense, quite apart from the proto-scientific sense in which he was original without parallel. But [Byron and other translators] couldn't, or wouldn't, get down to the level where syllables met each other and generated force. That had to be the aim, impossible as it seemed; to generate the force, both semantic and phonetic: the force of both meaning and sound. Indeed, in the original, some of the meaning was *in* the sound. Unless the translator did something to duplicate how the poem sounded, he, or she, wouldn't get near what it meant. James, 2013 (*op.cit*.; emphasis original)

The comment that James is pointing to the *thinginess* of Dante's epic is irresistible. Both poetry and ordinary language deliberately use multiple layers of meaning to express the *thing in view*. Ambiguity is built-in to poetic expression at a fundamental epistemological level: there is no unambiguous knowledge of a *thing in itself*. Scientists wish to speak unambiguously about the *thing* presently in view. But this is impossible in principle! What to do?

We have considered the example of the evolution of the idea of *entropy*, showing that at each stage the *thing in view* is replaced by an *idea* of the thing delineated in a natural language which aligns its salient features (that is, the properties of the thing then considered salient) with mathematical (that is, well-defined) ideas. This is a well-known progression that is usually presented as a version of solipsism, but that this cannot be the reality is demonstrated by the uniform belief of physicists that they are really describing the world as it is.

We have shown instead that although physics represents real knowledge about the real world, this knowledge is inaccessible in principle without the use of natural language, with all the ambiguity that entails.

Ultimately, physics relies ostensibly on this "natural" language, but used (as natural language often is) with poetic overtones: that is, with the intention of creating new meanings.

5. The Primacy of Language

St Paul said in 55 CE [ref.9], αρτι γινωσκω εκ μερους (*now I know in part*: I Corinthians, 13:12), but because we know things only partially does not mean we don't know any thing! Our survey of the idea of *entropy* has highlighted how partial our knowledge remains: even such a basic idea of physics remains controversial. However, even though the way we think of entropy has changed dramatically over the last century and a half, yet we can still obtain real and useful results. The fundamentals shifting beneath our feet is uncomfortable, but physicists are familiar with this feeling from the quantum revolution a century ago.

"*Knowledge*" is etymologically related to St. Paul's γινωσκω, as the OED notes (even the Latin "*science*" appears also to be a derivative of the ancient Greek γιγνώσκειν): the word carries the strong connotation of *personal experience* or *first-hand acquaintance*, as is seen in the Gospel ("*I know not a man*": ανδρα ου **γινωσκω**, Luke 1:34) echoing the *koine* Greek rendering of the ancient Hebrew ("*Adam knew Eve his wife*": Αδαμ δε **εγνω** Ευαν την γυναικα αυτου, Genesis 4:1; LXX), which text was almost certainly finalised essentially in its present (Hebrew) form before Homer, and was almost certainly then already an ancient text deriving from even more ancient oral sources. The idea of *knowledge* is ancient and has very deep roots for us, both ontic and epistemic.

We have spoken above of Creation: the climax of the first Creation account in the Hebrew Scriptures[72] (Genesis 1:26) is about the creation of mankind (man-and-woman together – for convenience, the English indicates the four Hebrew words):

Hebrew (unvocalised)	נעשה אדם בצלמנו כדמותנו
ποιησωμεν ανθρωπον κατ' εικονα ημετεραν και καθ' ομοιωσιν	LXX, c.3rd century BCE
Let-vs-make man in-our-image, according-to-our-lickenes [*likeness*]	Geneva, 1560

It is interesting that the Greek of the second half of the line might be viewed in terms of formal Welsh poetry[73] as (imperfect) *cynghanedd groes*: k-k-m-n / k-k-m-n (*<u>k</u>at ei<u>k</u>ona e<u>m</u>etera<u>n</u>* / *<u>k</u>ai <u>k</u>ath o<u>m</u>oiosi<u>n</u>*). Note that the LXX scholars considered that they did not have to repeat ημετεραν ("after <u>*our*</u> likeness": the possessive plural form is indicated in the Hebrew suffix) since the *cynghanedd* "sound" of the line allowed the hearer to imply it from the και. The Hebrew is already a consonantal text which can be transliterated as: *n'śh 'dm bṣlmnw kdmwtnw*, and vocalised as *na·'ă·śeh adam bə·ṣal·mê·nū kid·mū·tê·nū*. The second half of the line might be viewed as (imperfect) *cynghanedd draws*: m-n / m-(t)-n.

Of course, there is no virtue in pretending that Greek or Hebrew poetry can be forced into the formal rules of the Welsh *cynghanedd*: we here only wish to draw attention to the fact that, as for all poetry, the lines are composed with an ear to their *sound*, invoking both the *breath* and the *word* (and also, obviously, the *inspiration*). And the purpose of this iconic poetic text – a text that has been heavily influential in European cultural history almost up to the present day – is precisely to address the *ontological* questions: what is man? what is woman? who am I?

We have drawn attention to the antiquity of the roots of the ideas we have been exploring: the reason for introducing Hebrew texts is specifically that they are the most ancient remaining in current use. The Creation narrative in Genesis in the form we have it almost certainly dates from around the Temple reforms of Josiah in the 7th century BCE (see II Kings 23 and Margaret Barker's 1987 gloss on this[74]: p.142), and uses a modern Hebrew script (introduced in the early 5th century BCE). It has been widely thought that this narrative represented a theological innovation at that time, since comparable tropes had not been found in the surrounding cultures. But this position is certainly mistaken, since a reanalysis (by Korpel & de Moor, 2014[75, 76]) of two tablets from the Ugarit tell at Ras Shamra confidently dated late 13th century BCE show that the Ugaritic creation story has many remarkably close similarities with the Hebrew one. Therefore the traditional ascription of the Hebrew story to Moses (perhaps 16th century BCE or earlier) cannot be rejected out of hand.

Figure 1: **Bar Kokhba silver Shekel (134/5 CE).** *<u>Obverse</u>:* the Jewish Temple facade with the rising star, surrounded by [שמעון] ("Shimon"). *<u>Reverse</u>:* a lulav and etrog, the text reads: [לחרות ירושלם] ("to the freedom of Jerusalem") (the script is palaeo-Hebrew: see Supplementary Materials for more information) *<u>Image</u>:* Classical Numismatic Group, Inc. http://www.cngcoins.com, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2420146; *<u>Tracing</u>:* Margaret Barker

We should note that the Hebrew knowledge long predated and may have underpinned the Greek: Eusebius, citing precisely the antiquity of the Hebrew alphabet, insisted that "*Moses taught Plato*" (*Praeparatio evangelica*, c.320 CE; and see Barker 2003[77] ch.11).

It is known that the modern Hebrew script was preceded by a more ancient script, "palaeo-Hebrew"[78], in which the source documents for the modern text were probably written, and which is witnessed most famously by the "*Lachish Ostraca*", confidently dated c.590 BCE: these are letters in carbon ink on clay "ostraca" that appear to be military communications in the campaign during which the city of Lachish was lost to the Babylonians. This palaeo-Hebrew script was used by Simon ben Kosevah ("Bar Kokhba", leader of the second Jewish rebellion against

Rome 132-135 CE, bloodily put down by Hadrian) on the coins he minted for "Free Jerusalem" (**Figure 1**). But so far as we know, it was never used subsequently.

Light may be shed on the modern Hebrew canonical Biblical text by referring to a gloss in palaeo-Hebrew that has recently been found in the so-called "lead books" (see **Figure 2**): curious traditional artefacts that have recently come to light from Beduoin communities in Jordan that are "pages" cast in an impure lead with a sophisticated pattern in relief. Many such pages can be found, usually "bound" together in a "book". The presence of a form of palaeo-Hebrew on them indicates that the original design was passed down from the 2nd century CE at the latest, and probably earlier[§§]. A characteristic page is shown (the "Menorah" page, Figure 2) not only because it comments directly on our Creation text (Gen.1:26) but also because it comments in a way that clearly indicates the ambiguity and allusiveness characteristic of poetic texts that we have emphasised here. This Menorah Page can be read as a sophisticated and very extensive gloss on various aspects of Temple theology, quite possibly remembering the time *before* Solomon's Temple in Jerusalem was destroyed in 586 BCE by the Babylonians.

Figure 2: *"Menorah" page from a Lead Book*
Image (left) courtesy of Jean-Paul Bragard. ***Tracing (right)*** by Margaret Barker.
See Supplementary Materials for more information.

On the Creation text (Gen.1:26) for example, the Hebrew word for "*after-our-likeness*" is [כדמותנו] (*kiḏ·mū·ṯê·nū*) from the word [דמות] (*də·mūṯ*) which in this Page (Figure 2) is read from the three letters transliterated as [דמת]. The letter *waw* ([ו]) must be added to the transliteration following the rules known as *matres lectionis*: the original palaeo-Hebrew is a pure *abjad*, but modern Hebrew is slightly impure since some letters are used to indicate vowels. The Menorah Page (Figure 2) uses a modified palaeo-Hebrew, with Hellenised symbols as well as symbols indicating double letters: unfortunately, transliterating into a readable modern Hebrew script is not entirely trivial (see **Table 1** and **Supplementary Material**).

This word *likeness* ([דמת] *də·mūṯ*) can be found nine times in the Menorah Page, and if each triple and its mirror image is taken in three of its six possible permutations, we obtain the 10-line "poem"

§§ The alternative possibility that such artefacts were created for the antiquities market is considered in the **Appendix** (see **Supplementary Material**) and ruled out on the grounds that the palaeo-Hebrew is meaningful shown in Table 1. The first line of this poem is formed from [דמת] permuted twice, and the following nine lines are the nine mirror images, permuted the same way (see Supplementary Material for explicit details and discussion of the significance of reflections, especially **Figure A4**). There are of course other ways to read this mnemonic, but we have chosen the simplest coherent version available: a more extensive treatment is outside our present scope. It is interesting to note how the formal rules of modern information theory (involving the mathematical combinatorial and permutation operations) underpin the profound truths, as perceived by the creators of this ancient artefact.

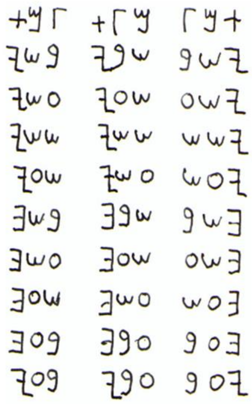
#	Palaeo-Hebrew	Modern	Modern+ML	English
0		תמד מדת דמת	תמיד מדת דמותו	continually / garments / likeness
1		ישב צבא בצי	ישב בצבא בוצי	enthroned / army / fine linen
2		ישע שעי עצי	ישע שעי עצי	he who saves / gazing on / tree
3		יצץ צצי צצי	יצץ צצי צצי	bloom / flowers of / my flower
4		יעץ עצי שעי	יעץ עצי שעעי	counsellor / my tree / delight
5		חשב שבח בצח	חשב שבח בצחיח	returns / praised / radiance
6		השע שעה עצה	השעע שעה עצה	delight / gazes / on her tree
7		העץ עצה שעה	העץ עצה שעה	the tree / counsels / he who gazes
8		העב עבה בעה	העב עבה בעה	cloud / overshadows / enquirer
9		יעב עבי בעי	אעוב עבי בעי	overshadow / my cloud / seeker

Table 1: ***Reading the Menorah Page (see Fig.2 and text)***

Line #0 is the three letters transliterated [דמת] (*də·mūṯ*, "likeness", Gen.1:26) with its permutations. This word occurs 9 times on the Page: lines ##1-9 are the corresponding mirror images (see ***Figure A4*** in **Supplementary Materials**). Hebrew is read right-to-left (the English is read left-to-right as usual). Readable modern Hebrew requires the addition of certain letters: the *matres lectionis*, see the column "Modern+ML". The transliteration (including ML and grammatical prefixes and suffixes) is described in Supplementary Materials. An abbreviated indication of the English translation is also given.

The "reflection" operation that yields the poem of Table 1 has a general importance. We have seen how Buckminsterfullerene [ref.46], and DNA and the Milky Way [ref.3] all have Maximum Entropy geometries precisely because these all involve *holomorphic pairs*: the logarithmic double spiral for the spiral galaxy, the double helix for DNA, a spherical double spiral for C_{60}, (and also, presumably, a pair of holomorphically bound "deuterons" for the alpha particle [ref.54]). "*Holomorphic*" is used here in its full mathematical meaning but applied to real objects, which can therefore be realistically thought of as *unitary objects*. "Two" have become "One" for all of these, and the two entities that form the holomorphic pair are reflections of each other.

Then the whole poem can be tentatively interpreted in English as:

0.	Clothed perpetually in His likeness	תַּמִיד מִדֹּת דְּמוּתו
1.	he is enthroned among the heavenly host in shining linen	יֹשֵׁב בִּצַבָא לָבוּשׁ בִּצִי
2.	delighting that I know he saves	יוֹשֵׁעַ שַׁעִי עֵצַי
3.	he establishes the flowering of my blooms	יַצִּץ צִצֵּי צִצַּי
4.	my Counsellor delights in me	יֹעֵץ עֵצִי שֹׁעֲעִי
5.	He returns in glory to praises	הַשֹּׁב שַׁבַּח בַּצַּחִיחַ
6.	he delights who gazed upon Wisdom's tree	הַשֹּׁעֵעַ שַׁעַה עֵצָה
7.	she blesses him with wisdom	הַעֵץ עַצָה שַׁעָה
8.	She overshadows the seeker	הַעַב עַבָה בֹּעֵה
9.	My cloud will overshadow him who enquires of me	אַעוּב עַבִי בֹּעִי
0.	Clothing him perpetually in the likeness	תָּמִיד מִדֹּת הַדְּמוּת

where we have also given the Hebrew original in a vocalised and slightly expanded version for the convenience of Hebrew speakers (see **Supplementary Material** for an extensive commentary).

This rendering interprets the literal text obtained from a simple 3-letter word (with its permutations and reflections), but indicates something of the mnemonic value of this Page. We have attempted to make the variety of allusions of the literal text explicit in the interpretation (see **Supplementary Material** for further explanations).

While exploring the meaning of *entropy* we have seen how we understand things. The ancient artefact shown in Figure 2 and interpreted above shows that such understanding is manifestly a property of our humanity that has been current for at least thirty centuries, where the underlying ideas date from at least a thousand years earlier. We are, and always have been, fundamentally curious about the ontological questions.

Physics uses analytical language, the language of mathematics, as central to the coherent definition and correct manipulation of complex ideas. But the activity of definition, essential to doing physics and a precursor to explicating meaning, is itself a delicate issue. We do not wish to fall into the error of Aristotle, who thought that his definitions had an ontic reality. But neither do we wish to fall into the opposite error of thinking that because we cannot define any real *thing* our definitions can have no reality at all. Indeed, although we cannot define real things, we can define our *ideas* of them, and we can then test these ideas against reality to see how far they are true. And insofar as our ideas are proved correct we can without solipsism claim a (partial) grasp of reality itself, a grasp that is both ontic and epistemic.

But how can we “grasp ideas”? For this basic purpose analytical language cannot help. The strength and purpose of analytical language is to construct logically valid arguments: one can check the *consistency* of one’s premises (or axioms), but one has simply to *assert* their truth. How do we form ideas that we are willing to assert axiomatically? How do we speak of them, and how do we understand others’ ideas?

6. The Poetics of Physics

Physics is the most definite and quantitative of all the sciences and, one might superficially think, the least *poetic*. Physics is the description of elemental matter – what could be simpler? what could be less poetical? Yet it turns out that we need poetry (or at least, poetic language) to be able to express our knowledge of what things are in themselves – especially such things to which common sense cannot apply – and it turns out that we also need this poetic language to discern how it is that we *know*. For prior to the sophisticated mathematical treatments that pervade physics is the *making of the terms* in which such treatments are done. Clausius said it in 1854: “*Bei dieser Bestimmungsweise … bildet …*”: we paint our picture (*Bild*) of things from our knowledge, and we try to make this knowledge as sure (*Bestimmung*) and as wise (*weise*) as we can (reinterpreting the meaning of Clausius’ text using the range of connotations audible in German and resonating with the Anglo-Saxon roots of much of modern English). Language always has a palette of meanings even if analysts (and physicists) try to eliminate the ambiguity that the poet relishes.

We have described the development of the idea of *entropy* over the last century and a half: entropy is a notoriously difficult concept, even though it is fundamental to modern physics. The different uses to which the idea of entropy has been put – the assertion of the impossibility of perpetual motion, the derivation of the ideal gas laws (and the design of steam engines), the design of telecommunications networks, the properties of black holes, the stability of galaxies – these all look so vastly different, and are thought of in such different ways that it is a great leap of the imagination to see any underlying common entity. In this essay we have tried to describe this imaginative leap.

Of course we do not assert that physics should (or indeed can) be done by poets (even if some poets may also be physicists, and some physicists poets). All must look to their own business. What we assert is that in the end the *understanding* of physics – indeed, the understanding of *any* thing – depends on inspiration. Physicists depend ultimately on language: what if our very language itself is endangered, as the Palikur poet of our epigraph bewails? Before it is anything else, language is poetry.

7. Conclusion

How do we sum up? We have drawn a distinction between poetic language, and the analytic language used for physics. We have shown that although analytical language is designed to be unambiguous, the ambiguity inherent in all language cannot be entirely eliminated but must emerge at the foundations of any scientific argument. This was illustrated by a discussion of the foundations of thermodynamics, and the meaning of the term "entropy" which has had surprising development continuing to the present.

Although *ideas* can be defined, real *things* defy definition: ultimately, our knowledge of them must be intuited, inevitably leaving space for ambiguity and incomplete understanding. Mathematics is a calculus of ideas, but even mathematics is not complete: the foundations of mathematics must be established with *meta*mathematical methods!

For many scientific purposes we can avoid the basic ontological questions, like: "*What is entropy?*" Provided we know how to calculate the quantities of interest we can be satisfied for practical purposes. But questions of a different nature require a more developed philosophical approach: How secure is the knowledge our scientific advisors claim to have? Why should I trust scientific advice? How do I evaluate conflicting advice given by various technical experts? Such questions have become particularly salient during the recent COVID-19 pandemic.

The answers to such questions depend on our basic understanding of what *knowledge* itself is. We have here sought to show how, at the very foundations of physics, we rely on a *poetic* handling of language even to define the terms we use to articulate the ideas we need to understand the world. Just as the foundations of mathematics are established with metamathematical methods, so the foundations of physics must be established with metaphysical methods.

But natural language is its own metalanguage: this is why ultimately we must rely on poetics. The *meanings* of things are always intuited: Leon Wieseltier has said[79], "*The knowledge of a thing is more decisive than the sight of it*" (p.22; note that we insist on the distinction between *information*, which is physical, and *knowledge*, which is mental). Formally, physics can treat only information: to treat knowledge we properly have to use metaphysics – or, ultimately, poetics. Wieseltier also said, "*The place of science in life cannot be scientifically established*" (*op.cit*. p.256), and McLeish ([ref.1] p.28 quotes Shelley: "*Poetry is … at once the centre and circumference of knowledge; it is that which comprehends all science*"[80].

We have explored the articulation of some basic ontological ideas with the help of a tangible artefact whose design appears to be very ancient, remembering times long prior to the Hellenic schools of philosophy. We have reconstructed from this artefact a mnemonic that makes an exceptionally sophisticated poetic gloss on the idea of [דמת] (*də·mūṯ*: *likeness*) which is a word in the Hebrew language with a similar set of connotations to Plato's "*forms*": that is, it is specifically concerned with the *knowledge* of things, underlining that long before "scientific" language was invented humans have *always* sought knowledge.

How do we *know* things? Rationality itself is as fundamental to poetic language as it is to analytic language: the appreciation of poetry depends critically on the recognition of poetic *form*. We have interpreted this artefact as a *mnemonic* of ideas looking back at least three millennia, probably much more: it focusses our attention on the logical continuity between different sorts of knowledge. We conclude that whether the knowledge is of concrete or numinous things, the *rationality* used to handle and articulate it is common.

Before anything else, language is poetic. The foundations of physics cannot in principle be established analytically: they must be constructed metaphysically, using the poetic properties of language.

Epilogue

God is One
Man is two: woman is too
Love is three: binding mankind whole
Right is four-square: breath of man and breath of woman
Mercy is prime five: both two summed with three and one summed with four
Mankind's number is six: love's mutuality
God's number is prime seven: the resting of creation
The first perfect cube conquers death: man and woman joining in life

References

1 Tom McLeish, *The Poetry and Music of Science* (Oxford University Press, 2019)

2 Owen Barfield, *Poetic Diction: a study in meaning* (Faber & Dwyer, London, 1928)

3 M.C.Parker, C.Jeynes, Maximum Entropy (Most Likely) Double Helical and Double Logarithmic Spiral Trajectories in Space-Time, *Scientific Reports* **9** (July 2019) 10779 (10 pp); http://dx.doi.org/10.1038/s41598-019-46765-w

4 Benjamin Lee Whorf, The Relation of Habitual Thought and Behavior to Language, *ETC: A Review of General Semantics*, 1(4) (Summer 1944) 197-215 (reprinted from *Language, Culture and Personality: essays in Memory of Edward Sapir*; Menasha, Wisconsin, 1941); https://www.jstor.org/stable/42581315

5 Michael Polanyi, *Personal Knowledge: towards a post-critical philosophy* (University of Chicago Press, Chicago, 1958)

6 Nicholas Maxwell, Aim-Oriented Empiricism and the Metaphysics of Science, *Philosophia* **48** (2020) 347–364; http://dx.doi.org/10.1007/s11406-019-00064-w

7 Martin P. J. Edwardes, *The Origins of Self* (2019, UCL Press, London); https://doi.org/10.14324/111.9781787356306

8 Textus Receptus (1550/1894), from the *Unbound Bible* (unbound.biola.edu), imported from *The Sword Project* (CrossWire Bible Society, crosswire.org): *Sword* module 2.4 (2014-04-13) (downloaded November 2020)

9 John A. T. Robinson, *Redating the New Testament* (SCM Press, London, 1976)

10 William Tyndale, *The Newe Testamente* (facsimile of the 1526 printing by Peter Schoeffer of Worms, The British Library, London, 2008)

11 Alexander Bird, Laws and essences, *Ratio* **18** (2005) 437-461; http://dx.doi.org/10.1111/j.1467-9329.2005.00304.x

12 Richard Rorty, *Consequences of Pragmatism* (University of Minnesota Press, 1982)

13 Richard Rorty "*Response to Ramberg*": essay in Robert Brandom (ed), *Rorty and his Critics* (Wiley-Blackwell, 2000)

14 Diana Green, Harold Green, *Yuwit kawihka dicionário Palikúr – Português.* (Associação Internacional de Linguística –SIL Brasil; SIL International, Dallas, 2010 & 2018)

15 Lesley & David Green, *Knowing the Day, Knowing the World: Engaging Amerindian Thought in Public Archaeology* (University of Arizona Press, Tucson 2013)

16 Magnus Course and Gillebride MacMillan, "Fishing, Gaelic and environment in the Outer Hebrides" In: McLeod, W., Gunderloch, A. and Dunbar, R. (eds.) C`anan & Cultar / Language & Culture. *Rannsachadh na Gàidhlig* **10** (2021). Aberdeen University Press: Aberdeen. ISBN 9781857520880

17 Michael Frayn, *The Human Touch* (Faber, London, 2006)

18 Wallace Stevens, "*Not Ideas About the Thing But the Thing Itself*" (in "The Collected Poems of Wallace Stevens"; Alfred A. Knopf, New York 1954)

19 Frank Wilczek, *Fundamentals: Ten Keys to Reality* (Penguin, 2021)

20 Augustine of Hippo, *De Civitate Dei* (413-426 AD; *transl*. John Healy 1610, *ed*. R.V.G.Tasker for *Everyman's Library*, J.M.Dent & Sons, London 1945)

21 S.W.Hawking, R.Penrose. The singularities of gravitational collapse and cosmology, *Proceedings of the Royal Society A* **314** (1970) 529-548; https://doi.org/10.1098/rspa.1970.0021

22 Gerald L. Schroeder, *The Science of God* (1997, Simon & Schuster, New York)

23 Richard Bauckham, *Jesus and the Eyewitnesses: The gospel as eyewitness testimony* (Eerdmans, Michigan, 2006)

24 K. Gödel, Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I (On Formally Undecidable Propositions of Principia Mathematica and Related Systems I), *Monatshefte für Mathematik und Physik* **38** (1931) 173–198; http://dx.doi.org/10.1007%2FBF01700692 (reprinted in English in: Stephen Hawking, *God Created the Integers*, Running Press, 2005)

25 Stephen Read, The Liar Paradox from John Buridan back to Thomas Bradwardine, *Vivarium* **40** (2002) 189–218; https://doi.org/10.1163/156853402320901812

26 Anselm of Bec, *Proslogion* (1078; *transl*. M.J.Charlesworth, Oxford University Press, 1965)

27 E.R.Dodds, *The Greeks and the Irrational* (University of California Press, Berkeley, 1951)

28 Thomas Piketty, *Capital et idéologie* (Éditions du Seuil, 2019; *Capital and Ideology*, *transl*. Arthur Goldhammer, Harvard University Press, 2020)

29 E.T.Jaynes, Gibbs vs Boltzmann Entropies, *American Journal of Physics* **33** (1965) 391-398; https://doi.org/10.1119/1.1971557

30 R. Clausius, Ueber verschiedene für die Anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie, *Annalen der Physik und Chemie* **201** (issue 7: "*Band CXXV*") (1865) 353-400; https://doi.org/10.1002/andp.18652010702

31 E.T.Jaynes, The Gibbs Paradox, in: *Maximum Entropy and Bayesian Methods* (Eds. C.R.Smith, G.J.Erickson & P.O.Neudorfer, Kluwer Academic Publishers, Dordrecht, Holland, 1992) pp. 1-22.

32 R. Clausius, Ueber eine veränderte Form des zweiten Hauptsatzes der mechanischen Wärmetheorie, *Annalen der Physik und Chemie* **169** (issue 12: "*Band XCIII*") (1854) 481-506; https://doi.org/10.1002/andp.18541691202

33 Paul Sen, *Einstein's Fridge: the science of Fire, Ice and the Universe* (William Collins, London 2021)

34 Jennifer Coopersmith, *Energy, the Subtle Concept* (Oxford University Press, 2015)

35 Roger Penrose, *Cycles of Time* (The Bodley Head, London, 2010)

36 Carlo Rovelli, *L'ordine del tempo* (Adelpho Edizione SPA, Milano, 2017; transl. Simon Carnell & Erica Segre: *The Order of Time*, Allen Lane, London, 2018)

37 Max Planck, Ueber das Gesetz der Energieverteilung im Normalspectrum, *Annalen der Physik*, **309** (1901) 553-563; https://doi.org/10.1002/andp.19013090310

38 Lars Lundheim, On Shannon and "Shannon's Formula". *Telektronikk* **98** (2002) 20–29; https://www.researchgate.net/profile/Lars_Lundheim/publication/251375021_On_Shannon_and_Shannon's_formula/links/59a3fa29aca272a6461b918b/On-Shannon-and-Shannons-formula.pdf

39 C. E. Shannon, "A Mathematical Theory of Communication", *Bell System Technical Journal*, **27** (1948) 379-423, 623-656

40 L. Brillouin, The Negentropy Principle of Information, *Journal of Applied Physics* **24** (1953) 1152; https://doi.org/10.1063/1.1721463

41 E.T.Jaynes, Information Theory and Statistical Mechanics, *Physical Review* **106** (1957) 620-630

42 Rolf Landauer, Computation: A Fundamental Physical View, *Physica Scripta* **35** (1987) 88-95

43 Charles H. Bennett, Notes on Landauer's principle, reversible computation, and Maxwell's Demon, *Studies in History and Philosophy of Modern Physics* **34** (2003) 501–510

44 M. C. Parker & S. D. Walker, A Unified Carnot Thermodynamic and Shannon Channel Capacity Information-Theoretic Energy Efficiency Analysis. *IEEE Transactions on Communications* **62** (2014) 3552–3559

45 M.C.Parker & S.D.Walker, Is computation reversible? *Optics Communications* **271** (2007) 274–277

46 M.C.Parker, C.Jeynes, Fullerene Stability by Geometrical Thermodynamics, *ChemistrySelect* **5** (January 2020) 5-14; https://doi.org/10.1002/slct.201903633

47 Jacob D. Bekenstein, Black Holes and Entropy, *Physical Review D*, **7** (1973) 2333-2346

48 S. W. Hawking, Black holes and thermodynamics, *Physical Review D*, **3** (1976) 191-197

49 S. W. Hawking, Black hole explosions? *Nature* **248** (1974) 30-31

50 M.C.Parker, C.Jeynes, Entropic Uncertainty Principle, Partition Function and Holographic Principle derived from Liouville's Theorem, *PhysicsOpen* **7** (2021) 100068 (11pp); https://doi.org/10.1016/j.physo.2021.100068

51 Arno Keppens, What Constitutes Emergent Quantum Reality? A Complex System Exploration from Entropic Gravity and the Universal Constants, *Entropy* **20** (2018) 335 (10 pp.); https://doi.org/10.3390/e20050335

52 Raphael Bousso, The holographic principle, *Reviews of Modern Physics* **74** (2002) 825-874

53 Michael C. Parker, Chris Jeynes, A Relativistic Entropic Hamiltonian–Lagrangian Approach to the Entropy Production of Spiral Galaxies in Hyperbolic Spacetime, *Universe* **7** (2021) 325 (15pp); https://doi.org/10.3390/universe7090325

54 M.C.Parker, C.Jeynes, W.N.Catford, Halo Properties in Helium Nuclei from the Perspective of Geometrical Thermodynamics, *Annalen der Physik* (2021, in press): http://dx.doi.org/10.1002/andp.202100278; preprint https://doi.org/10.21203/rs.3.rs-112066/v2

55 John Earman, The ''Past Hypothesis'': Not even false, *Studies in History and Philosophy of Modern Physics* **37** (2006) 399–430

56 Ilya Prigogine (in collaboration with Isabelle Stengers), *La fin des certitudes* (Éditions Odile Jacob, Paris, 1996; *The End of Certainty*, The Free Press, New York, 1997)

57 Robert C. Bishop, Nonequilibrium statistical mechanics Brussels–Austin style, *Studies in History and Philosophy of Modern Physics* **35** (2004) 1–30; http://dx.doi.org/10.1016/j.shpsb.2001.11.001

58 I.Prigogine, "*Time, Structure and Fluctuations*" (Royal Swedish Academy of Sciences: Lecture accepting the Nobel Prize for Chemistry, 8th December 1977)

59 Michael Stöltzner, The principle of least action as the logical empiricist's Shibboleth, *Studies in History and Philosophy of Modern Physics* **34** (2003) 285–318; https://doi.org/10.1016/S1355-2198(03)00002-9

60 Jennifer Coopersmith, *The Lazy Universe: An Introduction to the Principle of Least Action* (Oxford University Press, 2017)

61 David Bohm, A suggested interpretation of the Quantum Theory in terms of hidden variables I, *Physical Review* **85** (1952) 166-179

62 Carlo Rovelli, Relational Quantum Mechanics, *International Journal of Theoretical Physics* **35** (1996) 1637-1678

63 Alastair Rae, *Quantum Physics: Illusion or Reality?* (Cambridge University Press, 1986; 2nd Ed. 2004, reprinted with updates 2009, 6th printing 2018) p.137

64 Rolf Landauer, Information is Physical, *Physics Today* **44** (1991) 23-29; http://dx.doi.org/10.1063/1.881299

65 Luca Mari, Andrew Maul, David Torres Irribarra, Mark Wilson, Quantification is Neither Necessary Nor Sufficient for Measurement, *Journal of Physics: Conference Series* **459** (2013) 012007 (6 pp); http://dx.doi.org/10.1088/1742-6596/459/1/012007

66 Andrew Maul, David Torres Irribarra, Mark Wilson, On the philosophical foundations of psychological measurement, *Measurement* **79** (2016) 311–320; http://dx.doi.org/10.1016/j.measurement.2015.11.001

67 Alfred North Whitehead, *Process and Reality. An Essay in Cosmology.* Gifford Lectures Delivered in the University of Edinburgh During the Session 1927–1928 (Macmillan, New York, Cambridge University Press, Cambridge UK, 1929): corrected edition (eds. D.R.Griffin, D.W.Sherburne, The Free Press, New York, 1979). Page numbers are given for the corrected edition.

68 *The Geneva Bible* (Rowland Hall, Geneva, 1560), facsimile from the copies in the Chapin Library (Columbia University) and the Scheide Library (Princeton University) published by Wisconsin Press (1969), and republished by Hendrickson Publishers, Peabody, Mass. (2007)

69 *Septuaginta*, ed. A. Rahlfs (Stuttgart: Württembergische Bibelanstalt, 1935; repr. in 9th ed., 1971), from the *Unbound Bible* (unbound.biola.edu), distributed by the Center for Computer Analysis of Texts (CCAT) at the University of Pennsylvania (downloaded November 2020)

70 Sergio Rubin, Michel Crucifix, Earth's Complexity Is Non-Computable: The Limits of Scaling Laws, Nonlinearity and Chaos, *Entropy* **23** (2021) 915 (13pp); https://doi.org/10.3390/e23070915

71 Clive James, *Dante: The Divine Comedy* (Liveright Publishing, W.W.Norton & Co., New York, 2013)

72 BHS Hebrew Bible (Leningrad Codex) in Unicode with *Ketib* & *Qere*, distributed by CCAT (University of Pennsylvania): *Unbound Bible* (unbound.biola.edu). Transcribed from: *Biblia Hebraica Stuttgartensia quae antea cooperantibus* (A. Alt, O. Eissfeldt, P. Kahle ediderat R. Kittel; editio funditus renovata, adjuvantibus H. Bardtke *et al*. cooperantibus H.P. Rüger et J. Ziegler; ediderunt K. Elliger et W. Rudolph; textum Masoreticum curavit H.P. Rüger, Masoram elaboravit G.E. Weil). Deutsche Bibelstiftung: Stuttgart, 1977 (downloaded November 2020)

73 Mererid Hopwood, *Singing in Chains* (Gomer Press, Llandysul, 2004)

74 Margaret Barker, *The Older Testament* (SPCK 1987; reprinted Sheffield Phoenix Press 2005)

75 Marjo C.A. Korpel & Johannes C. de Moor, *Adam, Eve, and the Devil* (Sheffield Phoenix Press 2014)

76 C.Jeynes, *Review of "Adam, Eve, and the Devil" by Marjo Korpel & Johannes de Moor* (August 2014); http://dx.doi.org/10.13140/2.1.3318.7203

77 Margaret Barker, *Great High Priest* (Bloomsbury, 2003)

78 Graham Davies & J.K. Aitken, *Ancient Hebrew Inscriptions: Vols 1 & 2, Corpus and Concordance*, (ed. G.I.Davies; Cambridge University Press: 1991, 2004)

79 Leon Wieseltier, *Kaddish* (Alfred A. Knopf, New York, 1998; Picador, London, 1999)

80 Percy Bysshe Shelley, *A Defence of Poetry* (1821; in *Essays* …, Edward Moxon, London, 1840)

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