

Is prime matter energy?

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Oderberg, D. S. ORCID: <https://orcid.org/0000-0001-9585-0515> (2023) Is prime matter energy? Australasian Journal of Philosophy, 101 (3). pp. 534-550. ISSN 1471-6828 doi: 10.1080/00048402.2021.2010222 Available at <https://centaur.reading.ac.uk/102182/>

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To link to this article DOI: <http://dx.doi.org/10.1080/00048402.2021.2010222>

Publisher: Routledge

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To cite this article: David S. Oderberg (2022): Is Prime Matter Energy?, Australasian Journal of Philosophy, DOI: [10.1080/00048402.2021.2010222](https://doi.org/10.1080/00048402.2021.2010222)

To link to this article: <https://doi.org/10.1080/00048402.2021.2010222>



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Published online: 12 Jan 2022.



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Is Prime Matter Energy?

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ABSTRACT

This paper tests the hypothesis that the prime matter of classical Aristotelian-Scholastic metaphysics is numerically identical to energy. Is $P=E$? After outlining the classical Aristotelian concept of prime matter, I provide the master argument for it, based on the phenomenon of substantial change. I then outline what we know about energy as a scientific concept, including its role and application in some key fields. Next, I consider the arguments in favour of prime matter being identical to energy, followed by the arguments against this. The method used is that of ontological profile comparison: does the profile of prime matter match, in key features, that of energy? An affirmative answer, that $P=E$, would be a momentous discovery: it would show that one of the most neglected and derided ideas of pre-modern metaphysics—a contributor to its downfall in the wake of the Scientific Revolution—was *correct all along*. From a negative answer, we would still learn much about the interaction of science and metaphysics. It turns out, however, given what we currently know, that the answer is not quite as simple as one might hope.

ARTICLE HISTORY Received 4 February 2021; Revised 20 October 2021

KEYWORDS prime matter; energy; Aristotle; Aquinas

1. Introduction

The meeting of metaphysics and science is often a fraught affair. For a start, there is no precise meeting place. Space and time, for example, are phenomena that are fit and proper objects of both scientific and metaphysical study. Their analysis penetrates deep into both disciplines. They are not purely metaphysical in nature (as opposed to *substance*), nor are they purely scientific (as opposed to *momentum* or *Planck time*). No metaphysician (not even Aristotle) ‘imposed’ space and time on science, and no scientist ever imposed them on metaphysics. This is enough to demonstrate that there is no such thing as ‘pure’ science (or pure physics, in this case)—a discipline free of metaphysics. Nor is there ‘pure’ metaphysics—a discipline with no penetration by science. Both disciplines have their sub-domains in which the other has nothing to say and dare not tread—say, the metaphysics of essence or the biology of mammals—but we should not expect, in advance, that metaphysics is incapable of turning up in what might, at first glance, seem to be quite surprising scientific places, and vice versa.

It is in this spirit of mutual co-operation and understanding that I want to test the simple hypothesis that prime matter is energy. In other words, I ask this: is the classical, Aristotelian, metaphysical concept of prime matter no more, and no less, than what scientists—physicists, for the most part—understand to be energy? In short, is $P=E$? Whatever the answer, the examination itself is certainly worth undertaking, since it cannot fail to contribute to that mutual understanding so necessary for both sound metaphysics and good science. An affirmative answer, in particular, would be a momentous philosophical discovery (if I might dare to call it that). For it would show that one of the most neglected and derided ideas of pre-modern metaphysics—a contributor to its downfall in the wake of the Scientific Revolution—was *correct all along*. Not only correct, but *right there* under the noses of scientists and philosophers themselves, if only they had dared to speculate.

My answer to the simple question above will proceed as follows. First, I will outline the classical Aristotelian concept of prime matter and provide the master argument for it. (There are other arguments, to be sure, but no room to expound them here.) Second, I will outline what we know about energy as a scientific concept, not so much in the empirical details of this or that area, but in general—what it is and is not, its role, its application in some key fields, and so on. Third, I will consider the arguments in favour of prime matter being identical to energy. Fourth, I will examine the arguments against this. The reader will, of course, want to know my conclusion before anything else. To make for an interesting read, I urge the reader to wait. I can hint, however, that the answer is not as simple as one—not least myself—might wish it to be.

2. Prime Matter: What It Is and why It Is Real

Just to lay my metaphysical cards on the table, I am a firm believer in prime matter. As a neo-classical Aristotelian (as opposed, say, to a neo-Aristotelian such as Kathrin Koslicki [2018]), how could I not be? Aristotle calls it *prōtē hūlē* [*Metaphysics* IX (Theta) 1049a25, Ross 1928] or ‘first matter’. Aquinas calls it *materia prima* (first, prime, primary) or *potentia pura* (pure potentiality) (see *Summa Contra Gentiles* I.43.6, Pegis [1955: 166] and *Summa Theologica* I q.115 a.1 ad 2, Aquinas [c.1268 (1922): 153], for two among hundreds of references). By the nineteenth and early-twentieth centuries, the reality of prime matter was an entrenched commonplace of Scholastic philosophy—a non-negotiable metaphysical doctrine [Hugon 1927: 55–62]. Without it, the traditional Aristotelian metaphysic of substance, accident, causation, and change collapses.

Early modern philosophy, the Scientific Revolution, and the Enlightenment together ensured that prime matter ended up dead and buried. Descartes’s comment to Voetius that nothing of any use (*usum*) could be gained from prime matter, substantial forms, and ‘occult qualities’ pretty much set the tone for the dismantling of the Aristotelian edifice [letter to Voetius, May 1643, Adam and Tannery 1905: 26]. Nothing much has changed since then as far as the mainstream rehabilitation of prime matter is concerned, and yet there has been the occasional finger in the wind. No less than Werner Heisenberg writes thus [1959: 139]:

the experiments have shown the complete mutability of matter. All the elementary particles can ... be transmuted into other particles ... All the elementary particles are made of the same substance, which we may call energy or universal matter; they are just different forms in which matter can appear. If we compare this situation with the Aristotelian concepts of

matter and form, we can say that the matter of Aristotle, which is mere ‘potentia’, should be compared to our concept of energy, which gets into ‘actuality’ by means of the form, when the elementary particle is created.

The physicist Arthur Haas, who anticipated Bohr’s quantization of electron orbitals by several years, referred to ‘that unadulterated primordial something for which scientists sought through thousands of years, and from which all things amenable to sense perception are formed’, although he tarnished this sage observation by remarking that the ‘new physics’ had apparently bestowed the crown on *electricity* [1930: 65]. The philosopher and logician Patrick Suppes, in a less-known but fascinating paper, suggests that the doctrine of prime matter is an ‘excellent way’ of understanding high-energy physics [1974: 47]. Again in the context of microphysics, the philosopher of science Norwood Hanson wondered out loud whether prime matter might be the much-needed ‘unexplained explainer’ of certain particle interactions [McMullin 1963: 243].

So, what is the classical doctrine? It is hard to improve on the statement by twentieth-century Scholastic writer Bernard Wuellner. Prime matter is ‘pure passive potency of substance, without any form, species, or privation, and receptive of any forms or subsequent privations’. Alternatively worded, it is the ‘completely undifferentiated or indeterminate basic material of the physical universe, subject to all changes, informations, and privations’. Again, it is ‘the first intrinsic and potential principle of a corporeal essence’ [Wuellner 1956: 74]. There is no space here to unpack these extensionally equivalent formulations line by line, so to keep it concise I will sum up the doctrine by stating that prime matter is the formless and featureless underlying material substratum of *all* substantial change without exception: that is, all change from one material substance to another, whether living to non-living (or vice versa), or from one species of particle to another, one species of living thing to another, one chemical compound to another, or molecule, or mixture, liquid, crystal—anything and everything that is a substance.

Note that prime matter is *not* David Lewis’s ‘gunk’ since that is ‘an individual whose parts all have further proper parts’ [1991: 20]. Prime matter is not an individual and it has no parts (that’s just the concept; I am not defending it right now). Nor is it Ned Markosian’s ‘stuff’ [2015], which looks more like what an Aristotelian would call ‘undifferentiated secondary matter’—the propertied observable matter that takes on the features of whatever it constitutes: the stuff of chocolate is sweet and sticky, that of water is wet and transparent, and so on [ibid.: 5]. Not so prime matter, which is posited as featureless and unobservable. Whether we should believe in gunk or stuff is a good question, and tracing out the conceptual connections between either of these (whether or not they exist) and prime matter is a nice metaphysical task; but it is not my task here.

Of the various arguments for prime matter, the master argument is the one from substantial change: prime matter is a necessary metaphysical postulate because without it we cannot explain real substantial change. We do not need a technical (let alone Scholastic) definition of *substance* to make out the argument. All we need to claim is that some changes are such that the thing that changes—the bearer—ceases to exist during the process and a new thing comes into existence. In other words, the propertied subject that goes *into* a substantial change is numerically *distinct* from the propertied subject that comes *out* of it. (Here I use ‘property’ in the promiscuous analytic sense, not the narrower Scholastic sense. For more on this, see Oderberg [2011].) When my dog is groomed, the hairy creature that goes into the process is

numerically identical to the neatly trimmed one that comes out of it. The Aristotelian calls this an ‘accidental’ change. To use the familiar Aristotelian example, by contrast, when I eat a piece of celery the final products of digestion and metabolism are in no way numerically identical, either singly or collectively, to the piece of vegetable that entered my mouth. This latter example of substantial change is, metaphysically speaking, no different to the substantial transformation of particles in microphysics.

According to current physical theory, even quarks can be substantially transformed into other quarks: for example, a quark of one flavour can transform into a quark of another flavour through the weak interaction. In beta decay, where a neutron decays into a proton, an electron, and an electron antineutrino, one of the down quarks in the neutron decays into an up quark by emitting a W^{*-} boson. Such transformations are held to be consistent with the conservation laws, and according to quantum theory quark transformation must eventually occur. (See Rohlf [1994: ch. 18] for the details.) The point here is that the current ‘rock bottom’ level for physics, as for all previous putative lowest levels, involves (and must involve) substantial transformations. Such changes occur at all levels of physical reality, and prime matter is necessary for their possibility. (I note, without room for discussion, that the substantial nature of quarks is hardly a given, even among philosophers within the Aristotelian-Thomistic tradition: see, for example, Koons [2021] and Simpson [2021]. If quarks are not substances, then my argument applies to all of the other levels at which substantial change *does* take place.)

The only alternative to prime matter would be or entail the denial of substantial change altogether. The two main specific varieties involving such denial are, first, a series of literal *miracles* in the course of nature: appearances of substantial change would indeed be substantial but not real *changes*. Instead, they would be a series of annihilations and creations of old and new substances, respectively. For reasons too numerous to mention, I recommend that we not interpret the ordinary course of nature as a series of occasionalist miracles. The second alternative is that putative substantial changes are indeed changes, but they are not really *substantial*. Rather, they are the perennial arranging and rearranging of indestructible simple substances—the classic Democritean atoms. Among the numerous problems with this account, I take one to be in the grip of a theory if one insists that such metaphysical simples exist because the alternative is too unpalatable to swallow and despite the best endeavours of science ever to *find* such entities. We know how it goes with the supposed discovery of the ultimate ‘elementary particles’ constituting all things: high-energy physics simply gives the lie to any thought that some particles are exempt from real substantial transformation.

With that said, I have to enter two caveats, or rather appendices to the defence of prime matter given just now. First, the argument from substantial change is sound even if some substantial changes can be accounted for merely by the presence of enduring *secondary* matter. For example, suppose that a lump of calcium carbonate shatters into several smaller lumps. The original lump, a natural substance, has ceased to exist and has been replaced by some new substances made of the same secondary matter (what Markosian might call ‘chalky stuff’). Perhaps—and I take no position here—we can count that change as genuinely substantial and as explained by the persistence of enduring calcium carbonate. Prime matter would be surplus to requirements, with no role to play as the substratum of that substantial change. Prime matter *would* still be needed for those substantial changes—quark transformations, say, or other

microphysical or chemical processes—where there was no available secondary matter. Call these *total* substantial changes. So long as a single total substantial change happened anywhere in the cosmos, and we had no reason to regard it as a literal miracle, there we would need prime matter.

The second appendix is that no prime-matter-invoking substantial change need *actually* occur for prime matter to be a necessary metaphysical postulate. All that we require is that such a change be *possible*, not in some aetiolated logical sense but in the sense of metaphysical *potentiality*. If, for some substance, there is the real, intrinsic potential for it to be transformed into a new substance, there must be something in virtue of which such potential exists, in virtue of which it is, as it were, a standing metaphysical possibility. That would have to be prime matter—itself not just another material substance and not capable of any substantial transformation of its own.

3. What Is Energy?

The term ‘energy’ derives from Aristotle’s *energeia* (see, for example, *Metaphysics* 1045a25 ff., Ross [1928]), but, whereas Aristotle means *actuality* in his technical sense, our modern *energy* seems to denote the *opposite* half into which he thought all of reality was exhaustively divided—the correlative phenomenon of *potentiality* (*dunamis*). Stepping back, however, lest I be accused of prejudging the answer to my original question, we note that definitions of energy are hard to find. A standard textbook tells us: ‘Energy is a quantity that can be converted from one form to another but cannot be created or destroyed’ [Young et al. 2016: 196]. The one familiar to high-school physics students is that energy is ‘the capacity that an object has for performing work’ [Halliday et al. 2010: 183]. Nevertheless, Richard Feynman tells us this: ‘It is important to realize that in physics today, we have no knowledge of what energy is’ [Feynman, Leighton, and Sands 2005: 4-2].

Perhaps surprisingly, all of these *dicta* are music to the ears of an Aristotelian-Scholastic philosopher. Conversion from one form to the other is precisely that for which prime matter is the substratum, at least when the forms are substantial and not merely accidental. Again, prime matter is indeed a capacity—it is *pure* undetermined capacity—and the capacity for doing work (that is, for acting with causal efficacy) is indirectly *one* of prime matter’s general sub-capacities, along with the capacity to be worked (acted) *upon*. The exercise of either of these capacities—or potentialities, to use the preferred jargon—requires, for the Aristotelian, the combination of prime matter with forms both substantial and accidental. Moreover, although we should believe in prime matter, we have no knowledge of what it *is* in the sense that it does not fit into a classic Aristotelian definition by genus and species. It is not part of any taxonomic hierarchy, so in this sense is beyond classification. We can characterise it, of course, just as Feynman is happy and correct to tell us a lot about energy even though we do not know what it *is*, definitionally. That is why I spoke of a ‘statement’ or ‘formulation’ of what prime matter is, not a strict definition. Prime matter is, as has been said elsewhere, the closest thing that there is to nothingness without being nothingness. In all of this, we see the glimmers of various arguments for $P=E$, but first we need to look a bit more at energy in science.

Leibniz’s famous *vis viva* (living force) seems to be at the root of the modern conception of energy. (See Shimony [2010] for a good overview of the *vis viva* controversy between Leibniz and Descartes.) It was, he said, mass times velocity squared, and its total amount conserved. Thomas Young [1807: 52] appears to be the first to have

imported Leibniz's notion into modern usage, defining mv^2 as a body's 'energy' *simpliciter*. We now know that they were talking about *kinetic* energy, and that mv^2 is only conserved in perfectly elastic collisions; in an inelastic collision some kinetic energy will be converted to *potential* energy, and in all cases *total* energy is conserved.

As the nineteenth century progressed, rapid developments in industry and in basic physics and chemistry showed scientists that what Young, following Leibniz, had taken to be the 'living force' of nature was but one form of something fundamental, described by William Thomson (Lord Kelvin) as 'a principle pervading all nature and guiding the investigator in every field of science' [1881: 475]. Gaspard-Gustave de Coriolis identified 'kinetic energy' for what it was, William Rankine identified 'potential energy', and Lord Kelvin formulated the laws of thermodynamics, which itself became an entire branch of science devoted to identifying and studying energy transformations. We now have identified gravitational energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, and mass energy, among others [Feynman, Leighton, and Sands 2005: 4-2]. As Feynman says, each of these has its own equations yet each is but a manifestation of 'energy going in and out', always conserved in total.

These forms of energy are not, however, 'thing-like' objects possessed of various characteristics. As D.W. Theobald puts it, 'Energy cannot be identified, or re-identified like things'. It is not a 'simple substantive concept' but rather 'a way of describing the condition of any mechanical system'. Describing a system in terms of energy 'is not to assert that the system is in possession of any *thing*', any more than 'a man who behaves irascibly is ... committed to possessing a store of "anger"' [Theobald 1966: 41-2]. Gravitational energy is not itself a substance, energy, possessed of a gravitational property—such would be the stuff of a philosopher's conjuring. Rather, it is the potential energy possessed *by* a massive object in relation to another massive object due to gravity. Nor do we need to know what gravity *itself* is—say, a property of space-time as per general relativity—in order to understand gravitational energy in the way just stated. Similarly, chemical energy is the energy *of* a chemical substance, which is the potential of that substance to undergo chemical transformation. The same applies to all of the other kinds of energy: they *belong* to material substances; they are not themselves either many substances or identical to a single substance.

Yet although the various forms of energy belong to material substances—and derivatively to *systems* of material substances—they are all forms of a single underlying *quantity* of something or other—strictly indefinable, yet with a clear role in physical systems. It was the development and exploration of manifold new mechanisms for the transfer or transmission of heat, light, motion, force, and so on that required scientists to postulate an underlying transformable quantity enabling the different mechanisms to perform work (or to be worked upon, manifest various qualities, grow, shrink, and so on). If water can be heated by vibration, this must be because kinetic energy can be transformed into heat energy (the *mechanical equivalent of heat* thesis of Julius von Mayer). Again, if the mechanical energy of a turbine can be converted into electrical energy by a generator, there must be an underlying quantity in virtue of which such conversion is possible. Moreover, if efficiencies can minimise loss of energy through heat, for example, it must be that the lost energy is in principle recoverable: that is, it was never truly *lost* after all, merely converted into yet another form of energy that artifice and invention could (in principle) claw back.

4. Arguments for P=E through Profile Comparison

The simplest way to make out the case both for and against P=E is what I call the method of *profile comparison*. This can work well generally, when it comes to comparing concepts from two different disciplines—say, philosophy and science. We inspect the putative ontological profile of what one concept refers to, and see how it matches up against the profile of what the concept from the other discipline refers to. If they match sufficiently, then we have a strong reason for regarding the two concepts as referring to one and the same being or entity. Koslicki [2018: 41] is puzzled as to ‘how Thomistic metaphysics and fundamental physics could somehow converge on the very same ultimate substratum by different routes’. My simple answer is that if the profiles match then they do! As to how that could be so in some deeper sense, then, without embarking on a long tangent deserving of a paper in itself, I would suggest that if metaphysics and science study the very same reality, albeit from different perspectives, one ought to be surprised if such convergences *never* happened.

What, though, would a ‘sufficient’ profile match look like? We cannot answer with mathematical precision: there is no scorecard in the offing here. Rather, we look to see whether the *key features* correspond. I don’t say ‘essential’, since prime matter has no essence, strictly speaking, given that it belongs to no genus or species: it underlies them all in the material world. And I doubt that talk of the ‘essential features’ of energy would elicit anything beyond a wry smile from the likes of Feynman. We can use the term ‘essential’ in a loose sense if we like, but not much is to be gained. Better to say, for example, that obeying the conservation laws is a key feature of energy, just as indestructibility is a key feature of prime matter—something *true of* it. But let’s not jump ahead.

First, we have already noted that both prime matter and energy are preserved through substantial transformations. Recall Heisenberg earlier: *all* of the elementary particles can be transformed into other particles. This does not mean that *any* elementary particle can transform into any other one: maybe a muon cannot be converted into an electron (without neutrino partners), or maybe it can and the Standard Model has to be revised. Still, as long as *some* transformations can occur at the elementary level, we know that energy functions as the underlying substratum. Again, the impossibility of transmuting a butterfly into a pencil is consistent with the identity of prime matter and energy. For neither prime matter nor energy come in a *free* state—that is, free of the substances of which they are constituents. Prime matter needs form, and so does energy: they (recalling all the while that if P=E then ‘they’ are really *one*) always come *organised* whenever and wherever they are. This means that there will be *prior limits* on possible transformations. If prime matter/energy is organised into a butterfly, it cannot (as far as we know!) then be organised into a pencil. As said earlier, not just the actuality of some substantial transformations, but their mere *possibility* according to the laws of physics and metaphysics, requires an underlying substratum. As for prime matter, so for energy.

With that said, profile comparison supports more than preservation through transformation—namely, *conservation*. The conservation laws for energy are well established. Informally, the first law of thermodynamics holds that ‘there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes’ (Feynman, Leighton, and Sands: 4-1). Formally: ‘For every system, there is a scalar extensive [that is, additive] state function called *energy* (E).

When the system is isolated, the energy is conserved' [Ansermet and Brechet 2019: 9]. I will consider the quantitative question later, but for now I note that prime matter, too, is neither created nor destroyed in the course of nature. By 'creation' and 'destruction', both the physicist and the Scholastic metaphysician mean 'out of nothing' and 'into nothing'—that is, literal creation and annihilation. For the Scholastic, this is just part of the very concept of prime matter. The quasi-creation and quasi-destruction that occur in the ordinary course of nature are familiar to both physicist and metaphysician: both the combustion of wood to particles of ash, and the decay of a muon into an electron, an electron antineutrino, and a muon neutrino, are instances of the same general process of substantial transformation. None of the entities involved reduces to absolute nothingness: energy/prime matter are simply transformed, literally, by the taking on of new forms and the 'reduction', to use the Scholastic term, of the old forms back to potentiality. That is the only way in which prime matter (or energy) participates in anything close to destruction (or creation, the correlative process). Prime matter cannot *itself* be reduced to potentiality; it just *is* potentiality. Remember: I don't have to *justify* the claim that prime matter is conserved (although I could; yet another story for another day). All that I have to point out is that, on the classical conception, it *is* conserved. The material world divides exhaustively into actuality and potentiality: actuality (form) can be reduced to potentiality (as in substantial transformation); but there is nothing for potentiality itself to be reduced to except nothingness itself, which would be literal annihilation—not possible in the ordinary course of nature any more than creation *ex nihilo*.

Next—a profile point already suggested—neither prime matter nor energy exists in a free—that is, formless—state. Again, this is just how prime matter is—the intrinsically formless substratum that can only exist *when conjoined* with form into the metaphysical compound known as a material substance. The 'no matter without form' slogan of classical Aristotelianism covers both prime and secondary matter. Secondary matter, of its very nature, is informed: that is why it is called 'secondary' (perhaps, as I suggested, the same as Markosian's 'stuff'). It is not of the *nature* of prime matter to be informed—that would be metaphysical 'wongspeak' for an Aristotelian—but it is of the nature of material reality that prime matter always be conjoined to form. Why, though, *couldn't* we encounter prime matter in a free, formless state? Again, it is not part of my job here to answer that question, but I will happily gesture at a reason. To encounter *anything* in this world, it must be spatio-temporally bounded, occupying a finite region of space and time. Even the universe itself, if we could encounter it in an entire vision (perhaps via one of the increasingly sophisticated NASA images), would be spatio-temporally bounded—14 or so billion years in age and 92 billion light years in diameter, so we are told. But if we were to encounter free prime matter, it could have no spatio-temporal boundaries, since only form—actual organisation—can provide that. It is, however, metaphysically impossible to encounter, literally, anything material that has no such boundaries.

In physics, the term 'free energy' has nothing to do with the possibility of energy in a pure, unorganised state. It refers to such things as *available* energy to do work in a given kind of system—for instance, Gibbs free energy (the maximum reversible work available from a system under constant temperature and pressure) or Helmholtz free energy (the energy available for useful work in a closed system under constant temperature and volume). There is no free energy in the sense of energy in a pure state, not manifesting under one of the particular forms (kinetic, thermal, potential, chemical, ...) found in

particular systems. There is no direct measurement or observation of energy in itself; it has no intrinsic features—other than being the capacity or potential for work, broadly conceived—and no internal organisation; its only organisation is given by the forms in which it manifests itself. Once again, the profile comparison is positive.

Returning to the impossibility of a butterfly's transmuting into a pencil, note that there are also limits on energy conversion. Humans do not photosynthesise, so we cannot convert the radiant energy of the sun into chemical energy in the way that plants do. A firework explosion will convert chemical energy to sound energy, but it does not seem as though sound energy can be converted to chemical energy in any situation (that is, without mediation via another energy conversion). So, there are limits on the interconversion of prime matter into different substances due to the correlative forms involved, as there are limits on the interconversion of energy given the correlative kinds of energy involved—that is, the objects, processes, and systems containing that energy. In both cases, it makes no sense to ask whether energy or prime matter *itself* can be converted into anything. This is loose speak, the more precise questions being (i) whether, given the *substances* involved, the prime matter of *this* substance can, through substantial transformation, become the prime matter of *that* substance, and (ii) whether, given the kinds of energy involved (which depends on the kinds of object, etc., involved), this kind of energy can be converted into that kind of energy.

Moreover, the conversion limitations are general and specific in both cases, going beyond the truism that if, say, dogs cannot become cats then Fido cannot become Felix, and if sound energy cannot become chemical energy then the vibrations of a violin string cannot produce natural gas. For example, although mammalian gametes can transform substantially into an embryo (via gamete fusion), human gametes cannot fuse into a frog embryo. Correlatively, as we saw, although radiant energy can become chemical energy, this will not work in humans but it will work in plants. The million-dollar question, however, is that of whether the sets of possible and impossible energy transformations *map exactly* onto the sets of possible and impossible substantial transformations by the lights of classical Aristotelian metaphysics. Are the sets extensionally equivalent, simply approached from different directions? An affirmative answer will add strong support to a positive profile comparison, but there is no way of exploring that huge issue here. The answer has to be that we just don't know enough science, and we don't know enough metaphysics, to have an answer right now.

Another point in favour of $P=E$ is that neither prime matter nor energy has parts. 'Here is a piece of prime matter' makes as much sense to the metaphysical ear of an Aristotelian as 'here is a chunk of energy' does to the scientific ear of physicist. The mereological question is distinct from the quantitative question, with which I will deal later, saying for now only that the mere fact that something can be measured in quantities does not entail that it has parts (water) or even portions (gravity). That said, there is a kind of indirect, perhaps metonymic, way in which can we speak of prime matter as having parts. Given that the substantial compounds into which it necessarily enters have parts, then so does the prime matter of those compounds. Cut the branch off a tree and you have indeed cut off some prime matter that was a separable part of the tree—but *only* indirectly, in virtue of the branch that has prime matter as a metaphysical constituent (along with the arboreal form—lost when the amputation happens, but that's another story taking us from metonymy to Aristotelian homonymy [Ward 2008]). In other words, because a substance has prime matter, then if it is mereologically complex its parts have prime matter too, and to that extent only can we say that prime

matter, honorifically, has parts. The same is so for energy. When a speeding car clips an obstacle and loses a wing mirror, it loses some kinetic energy: a part of the kinetic energy of the car is lost. To that extent only can we say that *energy as such* is lost from the car. Maybe other energy is lost, too—say, the chemical energy of the molecules constituting the mirror. Again, however, it is only because of the specific forms that energy takes in certain objects that we can, in an honorific way, say that energy has parts.

So far, the case for $P=E$ based on ontological profile comparison looks quite solid, but an onslaught can be launched against it. Whether the defences are good enough will determine whether we are on the way to an answer.

5. Arguments against $P=E$ through Profile Comparison

In no special order, I begin with the conservation laws. We know that energy obeys them, but which metaphysician ever dreamed up those laws when thinking about prime matter? Not even Aristotle! That is a bit strong, actually, because as I intimated earlier it is not as though metaphysics has nothing to say about the creation and destruction of prime matter. For both are naturally impossible: only a literal miracle can produce something from absolute nothing and conversely. But what about the Big Bang? I, for one, do not think that the universe can have come into existence literally from nothing ([Oderberg 2018], following the well-known arguments from William Lane Craig), but even if it did this would qualify what we say about both prime matter *and* energy: the conservation laws would apply *within* the universe but not *to* it, which is what most physicists believe anyway. (This would also be the case if the universe were miraculously created, at least on any fairly conventional understanding of divine creation.)

In any case, the worry is that we know very specific things about energy—the conservation laws—that no metaphysician could ever know about prime matter, so how could $P=E$ be true? The reply is that the conservation laws are not obviously *inconsistent* with what we classical Aristotelians believe about prime matter. If they were—if the classical understanding involved the non-conservation of prime matter—then we would have a decisive refutation of $P=E$. Some *cousin* of P might be conceived, and we could ask the same question about that variant and its relation to energy; but $P = E$ as such would be false. Nothing about prime matter as classically understood, though, is contradicted by the energy conservation laws. So we should, the reply might continue, thank the scientists who, in the past couple of hundred years, taught the world things about prime matter that no one never knew—and that we metaphysicians could *not* have known. Why expect a metaphysician to dream up the conservation laws any more than all of thermodynamics? Isn't it just good methodology all round for metaphysics to learn from science, just as science learns (or should learn) from metaphysics? Note that physicists do not go around talking about amorphous substrata either, but why expect them to think in such abstract metaphysical terms? The irony here is that Koslicki [2018: 38–9] no doubt speaks for many when she accuses me and classical Aristotelians generally of 'metaphysical overreach'. Yet here is a case of metaphysical *underreach* or, better, of proper metaphysical modesty. Good metaphysicians know their limits, as do good scientists.

That said, it might be objected that $P=E$ looks shaky from the perspective of general relativity, where it is thought—albeit the topic is highly contentious—that the conservation of energy breaks down, or is perhaps undefined, or is not governed by any single set

of formulae ([Pitts 2021]; but see Gibbs [n.d.]). My claim, however, is *not* that prime matter obeys conservation laws, but that if energy *does* obey conservation laws, this is consistent with the ontological profile of prime matter. Isn't it, however, part of that profile that prime matter is indestructible? This is indeed the classical position, but the qualification 'naturally' is required. The Scholastics accepted that God could destroy prime matter, just as God could destroy (and did create) the entire universe and everything in it. This, however, is not the *ordinary* course of nature, but rather the stuff of literal miracles. Are we then to say that *if* conservation fails under general relativity (assuming GR to be the ultimate truth about the cosmic scale), this must be due to divine intervention? I would take this to count *somewhat* against $P=E$ because prime matter was introduced by Aristotle, and defended by the Scholastics, precisely to maintain the natural reality of substantial change. This reality is explicitly opposed to a highly occasionalist picture of nominal change consisting of real creations and annihilations, thus jeopardising the very methods of science as consisting of investigation into natural causal processes rather than into the workings of the divine mind.

I say 'somewhat', however, since the objection is not as strong as might appear, primarily for '*tu quoque*' reasons. For, as Pitts forcefully argues [2021], if energy conservation does fail in some situations, this removes one of the historically strongest objections to mind-body interactionist dualism. If dualism, of the strong Cartesian kind at least, is false, this will not be because it violates the conservation of energy, which, for all it seems, is violated on GR after all (or is perhaps ill defined). In other words, if the conservation laws do break down on some scale, potential problems pop up in various places. It might be a strike against $P=E$, but physicalists might also find a plank of their opposition to dualism removed, and physicists cannot escape the requirement of explaining precisely what happens to energy that literally vanishes on GR, say from the cosmic background radiation—assuming that it is not converted into gravitational energy, thus preserving conservation after all. Somewhat less defensively, the supporter of $P=E$ might insist that the highly contentious state of the conservation question in GR cannot, dialectically, be used as a cudgel against the equation; for we should not seek to explain the obscure by the more obscure.

Another objection to $P=E$ is simply stated: prime matter is not measurable at all, let alone quantitatively, whereas energy is both measurable and quantitative. Therefore, the profile comparison breaks down. A decent reply here, I suggest, hangs on what we mean by 'measurable' and 'quantitative'. If we consider the precise situation, we find no inconsistency between prime matter as classically understood and quantitative measurability. For energy *as such* has no measure, any more than does prime matter *as such*. Energy is measured as a constituent of objects, process, systems, and so on, and its common measure is joules: one joule is 'the work done when the point of application of 1 MKS [metres, kilograms, seconds] unit of force [newton] moves a distance of 1 metre in the direction of the force' [OICM 2006: 144]. The joule is a *derived* SI unit of measure, acting as a common unit of conversion for multiple kinds of energy in different situations. In practice, given diverse factors such as scale or customary usage, it is more convenient to use other units, such as calories in the case of nutrition (1 calorie = 4.184 joules) and electron volts in particle physics (1 electron volt = approximately 1.6×10^{-19} joules). If $P=E$, then *if* P/E is measurable, we should not be surprised that there is a *common* measure enabling full interconversion of all other units. So a common measure of prime matter is not in itself problematic.

The existence of a common measure, however, does not entail that there is some *pure* state of energy with that measure, any more than it does for prime matter. The joule is not a measure of energy *as such*—energy independent of its being contained in some object, process, system, and so on. It is a common measure in the sense of being a common unit of conversion between the particular kinds of energy—chemical, thermal, potential, kinetic, and the like—but this no more makes it a measure of pure energy than dollars, pounds, or roubles are measures of pure money *as such* even though all currencies can be converted into any of them. All distances can be converted into centimetres, but this does not make centimetres the measure of distance *as such* either. Joules embody a method of conversion, with a conventional definition in terms of force and distance; they do not measure pure energy, since there is no such thing existing *apart* from the objects, processes, systems, and so on in which energy is found.

When energy is measured, it is *always* in the context of the specific capacities for work of the objects involved. That is why a common unit such as the joule is meaningless unless translatable *back* into specific measurable situations. For example, one joule is the *kinetic* energy of a two-kilogram mass travelling at one metre per second. It is the amount of *electromagnetic* energy required to light a one-watt LED bulb for one second. It is the amount of *thermal* energy required to raise the temperature of one gram of water by 0.24 degrees Celsius. If there were such a thing as a unit of energy, such as the joule, that measured pure energy divorced from particular systems of work, heat, and related activity, then this *would* break the profile comparison since no such thing could apply to prime matter, which has no free state or free existence enabling pure quantifiability. It is always accompanied by form, and so whatever quantity it has depends on the forms by which it is informed.

The same goes for any other kind of measurability *as such*. Prime matter has no spatial dimensions *as such*, no qualitative measurement *as such*, and no other scale or dimension. Whatever it has depends on how it is informed. Every material substance has *weight* (let's not be distracted by photons; they can be dealt with as well), and so metonymic talk of prime matter as having weight would be wholly derived from proper talk of *secondary* matter—the matter of a substance such as my dog—having weight. Prime matter, as *matter*, and as *potentiality*, is a capacity for *taking on* spatio-temporal dimensions, as it is a capacity for taking on form. This means that the source of spatio-temporality, metaphysically speaking, lies truly in *matter*, not form. No physicist would (or should) disagree. But just as energy has no length—only the object containing a certain amount of a certain kind or kinds of energy—so prime matter has no length—only the substance consisting of secondary matter, that is, consisting of informed prime matter.

The Scholastics, thanks to Aquinas, have an even more specific and exact way of distinguishing between what we can truly say of prime matter *as such* and what is true of secondary or informed matter. Aquinas uses the term 'signate' matter (or 'designated' matter—*materia signata*) to refer to matter with determinate dimensions and capable of changing those dimensions within a range specified by the relevant form [Aquinas c.1256 (2007): 231]. The matter of a human being, for instance, has determinate dimensions for each individual human, and these change as humans grow from infancy to adulthood (and shrink in old age). But humans cannot be just any size: the human form specifies a range within which the human size must fit. This signate matter of a human is their secondary informed matter, considered in terms of dimensionality—*not* the prime matter that, when informed, exists *as*

secondary matter. Just as the measurability of energy can only obtain within the objects, systems, processes, and so on, in which specific kinds of energy exist, so the measurability of prime matter can obtain only within the substances (the constituents of various objects, systems, processes ...) in which specific kinds of informed matter exist—signate matter, that is, secondary matter considered dimensionally.

An objection that is a little easier to deal with is the thought that, whereas prime matter is purely passive, energy can be active as well as passive. Does this break the profile comparison? I doubt it. To the extent that one can speak of active energy, work done, and so on, this is a reflection of energy as informed in various ways. Active energy sometimes means energy available to generate further energy, such as electrical energy. Sometimes it means the kinetic energy of a moving system, or the energy required to do work. Passive energy sometimes means energy harnessed for consumption. Whether energy is active or passive, then, depends on its role or function in a given system. Considered in itself, it is the capacity for work. If $P=E$, the Aristotelian will translate the capacity for work into the pure potentiality to be informed in various ways. Depending on how the energy (prime matter) is organised, it will enable work to be done *to* an object or *by* an object (or system). If, for instance, the prime matter (energy) is organised or informed as a cow, it (again speaking in a derived or metonymic sense) will have the capacity both to act (walk, chew) and be acted on (rained on, herded). If it is organised or informed as a thermostat containing a thermocouple, it will have the capacity to be heated (passion) and might be able to switch on a boiler (action). Again, all of this is downstream from energy considered as such; the same prime matter. As such, energy (and prime matter if $P=E$) is the capacity to be organised or informed—and this is pure passivity.

Sometimes passive energy just means potential energy—which provides the perfect opportunity to dispel a related confusion. One might object that, whereas prime matter is pure potentiality, energy is potential in only one of its kinds—potential energy! The other kinds must be active, or actual, but they are not potential. So $P=E$ cannot be true. The defender of $P=E$ should reply that potential energy and pure potentiality must not be conflated. Potential energy is *stored* energy, as opposed to the energy of work or of some action being performed. It can be the potential energy of a system—gravitational potential energy, which is the stored energy of a massive object in relation to another massive object, and which is converted to kinetic energy when the former falls towards the latter due to its gravitational field. It can be elastic potential energy (a stretched or compressed spring). It can be the electric potential energy of a charge in an electric field. (See, further, Serway and Jewett [2008: ch. 7.6].) In all cases, potential energy exists in virtue of the actual configuration of an object or system: it is still *informed* energy and is only called potential because it is stored in the object or system. If $P=E$, then *all* kinds of energy, potential included, are cases of pure potentiality *actualised* in objects and systems.

We come to a trickier issue when we bring relativity into the analysis independently of the conservation problem discussed earlier. You might think that, in relativity (special and general), mass and energy are equivalent, and so $P=E$ and QED. Or you might think that mass and energy are *interconvertible* in relativity but not identical, and so $P=E$ is false—end of debate. Or maybe relativity has nothing to offer, one way or the other, when it comes to evaluating our hypothesis? Again, it would be a project in itself to assess prime matter in the context of the theory of relativity, and I am almost certainly not the person to undertake it. In brief, however, the situation

seems to be something like the following. Yes, because $e = mc^2$, energy is equivalent to mass in the sense that the total energy of a system is the total mass of the system multiplied by a constant, or, better, the total mass just is *all* of the energy of the system, including kinetic, potential, chemical, and any other forms. So, whereas mass was classically thought of as *quantity of matter*, relativity tells us that there is more to mass than that. Mass is a measure of *inertia*, and the addition of energy to a system, by applying a force, increases inertia and so increases relativistic mass (as opposed to rest mass or inertial mass, where no forces are at work). If I compress a spring by using one joule of energy, then the increase in potential energy of the spring is approximately equal to 10^{-17} kilograms of mass, leaving aside energy lost through heat. This gain is in principle detectible by a sufficiently sensitive instrument. We cannot simply equate mass and matter in relativistic physics, as we could on the classical picture. So far, $P=E$ is untouched. As for interconvertibility, what that means is best thought of in terms of units of conversion. Just as temperature measured in degrees Fahrenheit is convertible into temperature measured in degrees Celsius ($F = (1.8 \times C) + 32$), so mass/energy measured in some unit (for example, the SI unit of joules) is convertible to mass/energy measured in another unit (for example, the SI unit of kilograms). This, too, tells us nothing about whether $P=E$.

We are, however, left with the mystery of what exactly *happens* when the spring is compressed. Energy is put into it, we agree. But if $P=E$, this must mean that prime matter is put into it as well. What, however, could *that* mean? Well, when I compress the spring, then just as the spring gains a tiny amount of extra mass, so I *lose* the equivalent amount (minus energy lost through heat). That, too, is in principle detectible. What I have *not* lost, and the spring has *not* gained, is *secondary* matter. No atoms or sub-atomic particles have been added to the spring (leaving aside bits of skin and grease from my sweaty palms). But, as we have already seen, secondary matter is *not* energy; it is a *form* of energy, or, better, it is *informed* energy. And that form of energy—energy in the form of moving particles—does not get into the spring through being compressed. The change made to the spring is in the *binding* energy (a form of chemical energy) of the existing particles due to their rearrangement by compression. That extra energy is *stored* in the spring, to be sure, but not in the form of extra secondary matter.

So, what forms of energy *are* involved when relativistic mass is increased? It might be some form of chemical energy, or kinetic energy (as when an object is accelerated), or gravitational potential energy—usually a bit of all of these and more. Energy literally *moves* into the spring (to return to our example) under one or more of these forms, but never in a pure or free state devoid of form. If $P=E$, then we have to say that prime matter—not mass and not secondary matter—moves from me to the spring under the forms in which the correlative forms of energy are manifested. These are the forms of substances, whether moving or at rest, whether isolated or in systems, maybe even the forms of fields if we take into account the warping of space-time as the underlying reality of gravitational potential energy. It will, of course (for the Scholastic), never be merely substantial forms; it will be accidental forms as well—substances in motion, or at rest, or relationally positioned, or rearranged, and so on. The upshot of this frustratingly but necessarily brief analysis is that there does not appear to be anything in the deliverances of relativity theory that falsifies $P=E$.

A final objection (although no doubt there are others to be considered elsewhere) is that whereas prime matter is intrinsic to a substance, energy need not be. Potential

energy is relational (for instance, gravitational potential energy relating two massive objects and space-time), the kinetic energy of a moving object is relative to reference frame (although total energy is conserved in each frame), and so on. Prime matter, by contrast, is an *intrinsic metaphysical principle*, as much as substantial form is. So, they cannot be the same.

This objection has, I submit, less to it than meets the eye. If $P=E$, then energy cannot fail to belong intrinsically to objects (and derivatively to systems, events, processes) just as with prime matter. What accounts for relationality, then, will be various *forms* of energy, the ways in which energy is manifested in various situations. Just to emphasise: talk of ‘forms of energy’ is loose—not rigorous, as in the Aristotelian theory of substantial forms conjoined to prime matter and accidental forms conjoined to (inhering in) substances. Needless to say, if $P=E$ we will need to think about regimenting our talk of energy forms, but the loose locution is enough for responding to the intrinsicity objection. If we think of kinetic energy as relative to a reference frame, then having that particular form of energy for a moving object will be relational, but the underlying energy—of which kinetic energy is a form—will be intrinsic to the object itself. An analogy with simple Aristotelian metaphysics clarifies what this means. The prime matter of a substance is intrinsic to the substance. For it to have prime matter is not for it to be in relation to anything, definitionally speaking. But for prime matter to be the prime matter of a substance that is, say, to the left of another substance *will* be relational. Again, that prime matter is the matter of a substance is intrinsic; that prime matter is the matter of a *large* substance is relational. The parallel is precise because position and largeness are *accidents* of a substance, just as being in motion (and hence having kinetic energy) is an accident, as is being attracted by some other massive object (and hence having gravitational potential energy). By contrast, being the prime matter of a cubic substance is intrinsic, as is the possession of a certain quantity of internal binding energy. It is difficult to conceive of how energy *as such*—that is, abstracted from any particular form—could be anything *other* than intrinsic to objects; the same is so for prime matter. As such—abstracted from their forms (and they can only ever be abstracted since they do not exist in reality apart from their forms)—energy and prime matter are internal to the objects that have them. Which means that the present objection is no obstacle to their being one and the same. That said, if it turned out that physicists do not think of energy in this way, we would have a stronger objection to $P=E$.

5. Conclusion

What point have we reached? The case for $P=E$ is at worst *prima facie* plausible, at best quite strong. There are potential problems, in particular the role of energy in relativity theory and the conservation and intrinsicity questions. More work needs to be done on these, as well as on the many other issues to which the $P=E$ hypothesis gives rise. Suppose for now, however, that the case is strong: prime matter is identical to energy. Should we philosophers be scared? Should we think that science has actually validated a metaphysical postulate? Or—Heaven forbid—that metaphysics has validated a key concept in science?

I think that we should be scared if the case for $P=E$ meant we can do metaphysics just by doing science, as though prime matter ended up being an empirical discovery. That might, however, not bother philosophers as much as the reverse—that energy,

possibly the central idea of modern physics, was all along a metaphysical discovery, one made, moreover, by those pre-Scientific Revolution primitives of the classical era. My earlier remarks about overreach, however, should allay these fears. I see $P=E$, if true, as one example of that necessary rendezvous between science and metaphysics that *guarantees* that we are all studying the very same reality, albeit from different perspectives and with different objectives in mind. It is, then, more comfortable—and comforting—to regard the case for $P=E$ as a case for the essential appearance of a metaphysical postulate *within* science. It is not that one can do science *by* doing metaphysics, but that science cannot proceed *without* metaphysics; so we should be surprised if key metaphysical ideas did *not* emerge from relatively mature scientific thinking, as energy did. Mario Bunge [2012: 133] puts it thus:

Because it is ubiquitous, the concept of energy must be philosophical and, in particular, metaphysical (or ontological). That is, it belongs in the same league as the concepts of thing and property, event and process, space and time, causation and chance, law and trend, and many others.

So my answer to the question, Is prime matter the same as energy?, is not ‘yes’ or ‘no’, but: ‘why not?’¹

Disclosure Statement

No potential conflict of interest was reported by the author.

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References

- Adam, Charles and Paul Tannery, eds. 1905. *Œuvres de Descartes*, vol. VIII, Paris: Léopold Cerf.
- Ansermet, Jean-Philippe and Sylvain D. Brechet 2019. *Principles of Thermodynamics*, Cambridge: Cambridge University Press.
- Aquinas, St Thomas c.1256 (2007). *On Being and Essence* (De Ente et Essentia), in *Medieval Philosophy: Essential Readings with Commentary*, ed. Gyula Klima, with Fritz Allhoff and Anand J. Vaidya, Malden, MA: Blackwell Publishing (2002): 227–49.
- Aquinas, St Thomas c.1268 (1922). Volume 4 of *The ‘Summa Theologica’ of St Thomas Aquinas, Summa Theologica, Part 1, QQ.CIII–CXIX, literally translated by the Fathers of the English Dominican Province*, London: Burns Oates and Washbourne.
- Bunge, Mario 2012. *Evaluating Philosophies*, Dordrecht: Springer.
- Feynman, Richard, Robert Leighton, and Matthew Sands 2005. *The Feynman Lectures on Physics: The Definitive Edition, Volume I*, London: Pearson.
- Gibbs, Philip (n.d.). Energy Is Conserved in General Relativity. URL = <https://vixra.org/pdf/1305.0034v1.pdf>
- Halliday, David, Robert Resnick, and Jearl Walker 2010. *Fundamentals of Physics, Ninth Edition, Volume 1*, Hoboken, NJ: Wiley.
- Haas, Arthur 1930. *The New Physics*, 3rd edn., London: Methuen.
- Heisenberg, Werner 1959. *Physics and Philosophy: The Revolution in Modern Science*, London: George Allen & Unwin.
- Hugon, Édouard 1927. *Les Vingt-Quatre Thèses Thomistes*, Paris: Pierre Téqui.

¹ I am grateful to colleagues and students at the University of Reading for stimulating discussions on this topic, and to two anonymous referees for comments that have significantly improved this paper.

- Koons, Robert C. 2021. Thermal Substances: A Neo-Aristotelian Ontology of the Quantum World, *Synthese* 198 (Supp. 11): 2751–72.
- Koslicki, Kathrin 2018. *Form, Matter, Substance*, New York: Oxford University Press.
- Lewis, David K. 1991. *Parts of Classes*, Oxford: Basil Blackwell.
- Markosian, Ned 2015. The Right Stuff, *Australasian Journal of Philosophy* 93/4: 665–87.
- McMullin, Ernan, ed. 1963. *The Concept of Matter*, Notre Dame, IN: University of Notre Dame Press.
- Oderberg, David S. 2011. Essence and Properties, *Erkenntnis* 75/1: 85–111.
- Oderberg, David S. 2018. Traversal of the Infinite, the ‘Big Bang’, and the Kalām Cosmological Argument, in *The Kalām Cosmological Argument, Volume One: Philosophical Arguments for the Finitude of the Past*, ed. Paul Copan and William Lane Craig, London: Bloomsbury: 217–44. (Originally published in *Philosophia Christi* 4/2 (2002): 303–34.)
- Organisation Intergouvernementale de la Convention du Mètre (OICM) 2006. *The International System of Units (SI)*, Bureau International des Poids et Mesures; 8th edn. URL = <http://large.stanford.edu/courses/2018/ph241/carlton1/docs/si-8-mar06.pdf>
- Pegis, Anton C., ed. and trans. 1955. *Summa Contra Gentiles, Book 1: God, book 1 of On the Truth of the Catholic Faith (Summa Contra Gentiles)*, Garden City, NY: Doubleday.
- Pitts, J. Brian 2021. Conservation of Energy: Missing Features in Its Nature and Justification and Why They Matter, *Foundations of Science* 26/3: 559–84.
- Rohlf, James William 1994. *Modern Physics from α to Z^0* , New York: John Wiley and Sons.
- Ross, William D. 1928. *Aristotle: Metaphysics*, 2nd edn, Oxford: Clarendon Press.
- Serway, Raymond A. and John W. Jewett, Jr. 2008. *Physics for Scientists and Engineers with Modern Physics*, 7th edn., Belmont, CA: Thomson-Brooks.
- Shimony, Idan 2010. Leibniz and the Vis Viva Controversy, in *The Practice of Reason: Leibniz and his Controversies*, ed. Marcelo Dascal, Amsterdam: John Benjamins: 51–73.
- Simpson, William M.R. 2021. Cosmic Hylomorphism: A Powerist Ontology of Quantum Mechanics, *European Journal for Philosophy of Science* 11/1: 1–25.
- Suppes, Patrick 1974. Aristotle’s Concept of Matter and its Relation to Modern Concepts of Matter, *Synthese* 28/1: 27–50.
- Theobald, David W. 1966. *The Concept of Energy*, London: E. and F.N. Spon.
- Thomson, William 1881. On the Sources of Energy in Nature Available to Man for the Production of Mechanical Effect, *Science*, 2/67: 475–8.
- Ward, Julie K. 2008. *Aristotle on Homonymy: Dialectic and Science*, Cambridge: Cambridge University Press.
- Wuellner, Bernard J. 1956. *Dictionary of Scholastic Philosophy*, Milwaukee, WI: The Bruce Publishing Company. (Reprinted 2011 by Editiones Scholasticae.)
- Young, Hugh D., Roger A. Freedman, and Albert Lewis Ford 2016. *Sears and Zamansky’s University Physics with Modern Physics*, 14th edn., Harlow: Pearson Education.
- Young, Thomas 1807. *A Course of Lectures on Natural Philosophy and the Mechanical Arts in Two Volumes: Volume II*, London: Joseph Johnson.