Foundations of Physical Law
1 Introduction to Foundational Physics

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What do we mean by Foundations of Physics?

A risky business

A subject without status
career structure
financial support
impact
prizes
journals
protocols

For many people in physics, the subject simply doesn't or maybe even *shouldn't* exist.

So, why study it?

Because it’s the cutting edge. The real frontier.

That is why systems are not in place, and not yet an integral and essential part of physics.

Physics is a subject in which we are continually trying to push back to the ‘origin’ from a more complicated position.

We can’t lay down a generally-accepted basis until we reach the final discovery. The final goal is to find the starting-point.

Scientific method is mostly structured in precisely the opposite direction.

So, why study it?

We have to persist. The Standard Model of particle physics is brilliantly successful, but is only a *model*, not a theory.

All the facts are gathered into a coherent structure, but without any explanation. And the SM has been in place since 1973. We have had no major theoretical advance for forty years.

What is the problem?

Combination theories, for example, putting together GR and quantum theory, are not asking the right questions. If we want to truly reconcile GR and quantum theory, we have to find the foundations on which they are structured.

Foundations of physics is not particle physics, or GR, or QM, or any kind of extension or combination of them. It is a search for the explanations of such theories and the things that explain them.

A search for the common origins of all physical theories, and their common origin with mathematics. The ‘unreasonable effectiveness’ of mathematics in physics and of physics in mathematics.

What is the problem?

If we make progress in this direction, then we will certainly be able to explain many things in classical physics, relativity, quantum mechanics and particle physics, and possibly areas of science of greater complexity.

But this is like finding the technological consequences of blue skies research.

We know that it will always happen, and we are happy to see it happen, but it is not the research's primary purpose.

How do we study it?

Foundations of physics is not only a separate discipline within physics.

It also requires a completely separate way of thinking and methodology, intrinsically difficult and not yet included in any formal description of scientific method.

Scientists have always used *induction* to infer a cause given certain consequences, but, in studying foundations, this inductive approach needs to be taken to an extreme level.

How do we study it?

The causes are much more general than the ones we usually investigate, and this requires a much more imaginative and wide-ranging style of thinking than our training in the method of deduction from accepted starting-points, with perhaps a few carefully-limited inductive inferences, will allow.

It means ‘thinking outside the box’ where the ‘box’ is physics as we have been taught to understand it. Not trying to contradict this physics but trying to find something which may *look* different, and will certainly be simpler, but which automatically will give us the familiar structure when we make the connections. If we don’t recognise this, then we have no hope of making progress.

How do we implement the process?

Random speculation no use without protocols.

We need a theory of knowledge more fundamental than the knowledge we want to generate.

Need a *philosophy*, a ‘meta’-physics, perhaps even a ‘metaphysics’

Not ‘philosophy’ as usually talked about
Not ‘philosophy of physics’
Not ‘philosophy of science’

How do we implement the process?

Need ‘philosophy of knowledge’, strictly geared to working in Foundations of Physics.

A highly technical process – aims to find those more fundamental principles of knowledge which will help us to choose fundamental principles for physics, and recognise them when we see them.

We could never do this from scratch. Need a symbiotic process developing the philosophy along with the physics in a continual feedback loop.

If we are successful, can begin to codify the principles for use in other cases.

Our current picture of the world

How did we develop a picture of the world which is very different from the one we normally perceive, and often contradictory to our expectations?

We have evolved as highly complex beings in an equally complex environment. We perceive at 15 orders of magnitude bigger than the size of the proton and neutron.

These are themselves structurally complex but the complexity they create in helping to produce the world as we perceive it is on a stupendous scale.

Our current picture of the world?

Complexity leads to *emergent* properties not seen at a less complex level

These are the ones that we will naturally consider as ‘normal’

Hundreds of years of investigation have shown that we can be deceived.

One of the most ‘certain’ ideas we had was that there was such a thing as solid matter and substance

Now we know that solidity and materiality are only emergent properties. No extended objects. ‘Material’ objects just a distribution of interacting points in otherwise empty space.

Our current picture of the world

So how did we manage to develop this view?

We used the one real talent that we have – *pattern recognition*

Nature seems to reuse the same patterns at different levels of complexity, a self-similarity and perhaps a fractal structure built into its very code.

So we use patterns observed at one level to explain what occurs at another, and observe more sharply those aspects in which the pattern does not recur.

Mathematics a classic example of self-similarity, a kind of coding of the whole process.

Foundations not complex

Pattern recognition is one of the most important components in ‘thinking outside the box’.

Mathematical structures are at the heart of physics, but must somehow reflect the transition from relative simplicity at the foundational level to more highly developed ones as more complex structures emerge from the foundations.

A highly complex mathematical model can’t be a *foundation*.

Ptolemy’s epicycles not the ‘real’ answer.

Foundations not complex

But ‘simpler’ mathematical structures we use must be capable of leading by a natural progression to the more complex ones already in place.

Mathematics and physics intimately connected – mathematics not simply a ‘tool’ used in physics. Deeply built into the structures that physics needs for its foundations.

Simplicity is the key

The progression is always from simplicity at lower levels to complexity at higher levels, never the other way.

Explaining complex systems using complex mathematics doesn’t help us to understand the foundations.

One particularly significant type of pattern has become of immense significance, an indication of how our mathematics can start from something seemingly simple and lead to something clearly complex.

Symmetry

This is *symmetry* – all about us in the laws of physics, the fundamental interactions and the fundamental particles.

Symmetries help us to decomplexify explanations, and, if we know where it comes from, may lead to more profound understanding.

Some symmetries are *broken*. What is fundamentally symmetric appears, under certain conditions, to display some asymmetry.

Reason not arbitrary, and we need to discover it. Definitely not *fundamental* – nature never acts in such an arbitrary way. In some way, a sign of complexity or emergence.

Avoiding the arbitrary

Avoiding the arbitrary a cardinal principle

You can’t subscribe to physics only up to a point.

Has to be the total and final explanation.

No point at which you say ‘this is where physics ends’.

Has to be true without exception. Believing in its unqualified truth has been the source of its unique strength as an explanation of the universe.

The need to be uncompromising

If we decide a direction is the right one we have to be extreme in implementing it, utterly ruthless in pushing it to its limits.

For example, it is clear that physics, in its foundations, must be totally abstract, exactly as quantum mechanics would suggest.

The idea that ‘real’ or ‘tangible’ ‘objects’ and purely abstract concepts like space and time can exist simultaneously in our physical picture is a logical impossibility. They have to be all of the same type.

The need to be uncompromising

All the evidence, including experimental results on the point-like particles, suggests that the 'true reality' is the abstraction

'Tangibility' only an emergent property at a higher level of complexity.

Only complete abstraction brings about link with mathematics.

Quantum mechanics not a 'calculating device', but an exact indication of the way physics should go at the fundamental level.

This is not only what physics is like, but what it *should be* like.

The need to be uncompromising

We should look for something that is staggeringly simple, yet somehow capable of generating complexity.

If our *basic* idea is a complicated construction, say a 10-D space-time, then we have no way of knowing how this breaks up into the simpler component parts that must exist because we have no *fundamental* mechanism for doing this.

The need to be uncompromising

If, as string theory says, the symmetries required by nature, need 10 dimensions,

we should expect to find them by working out how such a complex idea emerges from simpler ones,

in which the structures of the *components* reveal them as diverse in origin, the ‘brokenness’ of the larger symmetry coming from its inherent complexity,

not by some arbitrarily-imposed concept of ‘symmetry-breaking’. Broken symmetries are a sure signature of complexity, not of simplicity.

Avoiding model-dependent theories

Once we start working purely with abstractions, *models* become meaningless.

Needed when we reach complexity, but no model lies at the foundations of physics, only pure abstraction.

At all times, we go for absolute minimalism. Abstraction is minimalism in its final state.

Ockham's razor best exemplified by ideas in which everything is there only for an abstract reason, all additions, made for our complexity-driven mode of comprehension (the 'story-book' picture), removed.

Totality zero

We have removed everything except physics.
We have removed everything from physics except abstraction.
Surely, we can now start from the abstractions?

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Is there a principle which can encapsulate this? Yes: *zero totality*.

The universe and everything within it, including all the conceptualising that we can do about it, is absolutely nothing. The only position that makes logical sense. Complete zero is the only concept we can imagine that would not be arbitrary if unexplained.

Totality zero

Richard Feynman, the negative gravitational energy of the Hubble universe effectively cancels out the positive mass energy: ‘It is exciting to think that it costs nothing to create a new particle, since we can create it at the center of the universe where it will have a negative gravitational energy equal to $M_{tot}c^2$. – Why this should be so is one of the great mysteries – and therefore one of the important questions of physics. After all, what would be the use of studying physics if the mysteries were not the most important things to investigate.’

Cosmologists, everything starting from ‘nothing’, or zero space, time and matter.

Totality zero

Peter Atkins: ‘the seemingly something is elegantly reorganized nothing, and … the net content of the universe is … nothing’ (*Creation Revisited*, Harmondsworth, 1994, p. 23).

Even classical physics based on the idea that the total force in the universe must always be zero – to every action there is an equal and opposite reaction.

The reason for symmetry

The need to make everything total exactly zero explains why symmetry is so important at the deepest level.

Symmetry (and, in particular, *duality*) provides a clear way of having totality zero and yet allowing things to happen.

Should not be a problem for physicists, who, for example, say that two objects will fly apart with zero total momentum, and yet each object has a nonzero momentum of its own.

The reason for symmetry

To introduce it as a *general* principle, we have to imagine that the real zeroing happens at a subtle foundational level, and that apparent asymmetry or symmetry-breaking will come with complexity.

This can (and will) be justified at a later date (and will be) when we look at how complex systems develop from simpler abstract notions.

For the moment, we will accept that this is a principle which, like all the others, applies, at the foundational level, *without exception*.

Methodology now in place

Foundational ideas need to be

- simple
- symmetrical
- mathematically-based
- minimal
- totally abstract
- and combining to a zero totality

These conditions to be applied rigorously, ruthlessly, and in all cases without exception.

Nothing arbitrary in the picture, and final 'structure' *totally exclusive*.

Strict protocols

We now have strict protocols for a foundational approach.

At this stage we want to exclude everything extraneous, to reduce the options to the only ones that are compatible with a foundational theory as we perceive it.

The strictness is absolutely essential, as we are reaching the absolute limit of what it is conceivable to know.

But this is just the first step. We haven't yet established what the protocols will apply to – and this is a very important question.

What are the most primitive physical concepts?

What concepts fulfil these conditions? These will be the most primitive physical concepts imaginable.

Go back to the idea that the whole human development of science is only possible because we have the capacity to recognise repeated patterns.

What we find is that, descending from the large-scale complex structures to increasingly small-scale and less complex ones, certain concepts seem to be necessary at all levels (for example, space and time),

while others (solidity, materiality) are ‘emergent’ and disappear at the less complex levels.

What are the most primitive physical concepts?

This suggests that the repeated concepts may appear at the most primitive level, while the ones which are not repeated will not.

Using this kind of analysis we can put forward a provisional set of 'primitive' concepts (ones which cannot be broken down any further or discarded as emergent) which we can test against our protocols.

The full account will be given in the third lecture after we have established some necessary mathematics.

What are the most primitive physical concepts?

But, it is clear that they must include space and time,

but *not* space-time, which is emergent (otherwise we could not explain the differences between the components – another broken symmetry!),

and certainly not curved space-time, which is even more emergent.

Something must represent matter in its point-like state

and something else energy or the connections between the points.

What are the most primitive physical concepts?

There must also be some way in which, at the foundational level, these abstract concepts are delivered, all at once, as a ‘package’,

explaining the growth of complexity in the way the packaging occurs.

What will this structure look like?

Whatever we find won't immediately look like physics as we now know it, any more than a cluster of cells looks like a human being,

but, as we unravel the complexities, we will see that familiar physics will begin to appear, and with a greater clarity than it ever previously had.

What will this structure look like?

People have long had an expectation that some great complex equation will hold all of nature's secrets, but nature doesn't work like that at all.

The primitive 'structure' will certainly be mathematical, but it won't be an equation. Its secrets won't be immediately obvious. They will have to be teased out one by one, as the complexity develops.

This is physics at a primitive, embryonic level, an *Ur-Theorie* if you like. It requires inductive thinking, a kind of X-ray vision which penetrates through the layer upon layer of complexity to the primitive core – deductive mathematical techniques won't help us.

What will this structure look like?

But the severity of the criteria we have established and the exact mathematical basis will ensure that it is rigorous.

And it will begin to answer those questions, like

> what are space, time and matter?
> why is space as we observe it 3-dimensional?
> and why does time never run backwards?

that we may have thought could never be answered.

The End

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