

The Book of Lumen

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FEATURE

Light plays a central role in the creation stories that come down to us from antiquity. A widely known example is found in the book of Genesis (written ca. 1450-1400 BC). In the English-speaking world, this poetic account of origins was read for over 400 years in the Elizabethan English of the King James Version (KJV, 1611). Because much of the work on classical optics was contemporary with the writing and dissemination of the KJV, we thought it would be fun to imagine how KJV scribes would tell the history of the physics of light.

DISCLAIMER: In this work we intend no mockery of any person, deity, nationality, philosophy, or tradition. Conversely, this is not an advertisement for any religious persuasion or cultural group. We merely adapt to our purposes the KJV as literature, borrowing its style and some of its well-known passages for their antique eloquence. By telling a bit of physics history in this out-of-character way, we hope to generate a lighthearted look at ourselves, without offense. Lest we err on the other side and sound excessively pompous, we recall that early KJV editions acknowledged the patronage of "our dread Sovereign James I," and hope our readers find this version of physics history not too dreadful.

CHAPTER 1

In the Beginning the universe was without form, and void; and darkness was upon the face of the deep. And the Spirit of Broken Symmetry moved upon the face of the vacuum.

2 And the Spirit said, "Let there be light." And there was Light, which cometh in a big bang, producing particle-antiparticle pairs. And the Spirit saw that it was good.

3 And in a great annihilation did the particles and antiparticles begat more light,

4 And in their asymmetry the nucleons did appear. And the evening and the morning after nucleosynthesis was the first day.

5 And it came to pass, after a thousand billion days, that the particles of matter fell together in nebulae of dust. Then did the dust of the firmament condense into the Sun, and brought forth new light.

6 After many days was the dust formed into People filled with Intelligence and Awe. Then there arose among them certain Wise Men called Philosophers, asking, What is Light?

7 Saith the philosopher Pythagoras, Light is sent forth by luminous bodies, and ye beholdeth vision when the light entereth thine eye.

8 But others said, Nay, the eye searches for objects and sendeth forth the light. Socrates, Plato, Euclid, and the Sophists were among these.

9 And there was great division among the Philosophers, as they argued continually.

CHAPTER 2

1 And in the fullness of time there arose a mighty prophet called Galileo, preaching in the kingdoms of Pisa and Venice and Padua,

2 Saying, Experiment ye, for the Way of Physics is at hand.

3 Learn of Nature by putting thy questions directly to Nature, who telleth the truth, and lieth not. And the people marveled at the boldness of his teaching.

4 They hearkened unto his voice, and lifting their eyes began to measure heaven and earth in a multitude of experiments.

5 And again the people asked, What is Light? Inasmuch their experiments with stones and seas lead them to divide the world into Particles and Waves, the people believed that either Light must be Wave, or Light must be Particle.

6 Some taught the Wave doctrine, and others taught the doctrine of Particles.

7 Then came Robert Hooke, saying, Light is Wave, for behold how thin films, when illuminated with uncoloured light, produce divers colours.

8 And lo, these colors appear only when the film's thickness lieth between narrow limits. Wist ye not that Colours must be finely tuned, like strings of the harp? Therefore must Light be Wave. Many wondered at this.

9 But the people knew not the speed of light. From Galileo's experiment with twain lanterns, they knew only its speed to be great beyond measure.

10 Then rose up Olaus Roemer, who saith, Know ye that the moons of Jupiter, in their orbs about that mighty planet, maketh a clock that we see by the light of the golden sun. Behold, the clock of moons loseth time as the earth recedes from Jupiter.

11 Saith Roemer, If this delay be due to the finite speed of light, then must that speed be hundreds of millions of furlongs per hour.

12 Knowing therefore the speed of light to be great but finite, Christian Huygens did write the first systematic epistle that Light is Wave.

13 Saith Huygens, No bulk matter could travel with so great a speed. But lo, a wave may travel so fast.

14 For consider ye a row of polished stones: smite one end of the row, and at once the stone from the opposite end flieth away, even though the entire row moveth not.

15 Yea, saith Huygens, a disturbance travels down the row, like unto a wave.

16 And if Light be Wave in the ether, saith Huygens, then each point on the wave front becometh the source of another wave. And Huygens with his construction did derive the observed laws of refraction and reflection, and the people rejoiced to see it.

17 Then did Huygens with his construction prophesy that light, if it be Wave, must therefore travel into the geometric shadow. This was called Diffraction, and some searched diligently for it.

18 Few among them knew that before Huygens had prophesied, Grimaldi beheld how a needle, when placed in a beam of purest light, shewed the broadening of its shadow, with fine fringes at the shadow's edge. And Grimaldi was the first to say, Let it be called Diffraction.

19 But many persons, seeing not the diffraction that Huygens predicted and Grimaldi witnessed, hardened their hearts against the wave doctrine, and believed not.

CHAPTER 3

1 And it came to pass in those days that a plague swept the kingdom of Great Britain, and the students were sent home.

2 And one of these students, Isaac Newton, returned to the land of his fathers and there meditated upon mathematics and philosophy.

3 And as he meditated, Newton beheld the celebrated Phenomenon of Colours, how white light, upon passing through the prism, emergeth in all the colours of the rainbow.

4 Then saith Newton, light is not merely changed by the prism, as men have said.

5 For if that were so, then a second prism should change the colours even more, but lo! the light that emergeth from the second prism is as white as before.

6 And Newton pondered these things in his heart.

7 Then he saith, Verily, verily, I say unto thee, the light wast not changed by the prism, but separated. In the two prisms the white light hath been taken asunder into colours and put back together again. And it was so.

8 Then did the fame of Newton spread throughout the land.

9 And Newton performed thin film experiments similar to the deeds of Hooke, and beheld what later generations would call Newton's Rings.

10 Like Hooke, Newton saith, Something periodic is wrought when light passeth through the refractive medium.

11 But unlike Hooke, who believed the periodicity to be within light, Newton saith, The periodicity is caused by something which refractive matter doeth unto the light.

12 Saith Newton, Every ray of light in its passage through any refractive surface is put into a certain transient state.

13 And Newton remembered Grimaldi's diffraction, but hearkening how gravitation acteth over a distance, Newton saith, Do not Bodies act upon light at a distance, to put light into a transient state?

14 Behold, Are not the Rays of Light very small Bodies emitted from shining substances? For such Bodies will pass through uniform Mediums in right lines without bending into the shadow.

15 And thus did Newton preach the gospel of Light as Particle, and many believed.

16 But one who did not believe was Leonhard Euler, who taught that light was produced by small vibrating bodies, but the ether carries the vibrations as waves to the eye.

CHAPTER 4

1 And it came to pass, that the Physicists walked in the valley of the shadow of insufficient data, and could clarify not the question that burned in their hearts, saying, Doth light consist of Particles, or of Waves?

2 Some sought the truth in refraction, where the incident ray, upon entering the water from the air, doth bend towards the normal.

3 Seeing the ray bent towards the normal, the physicists said, Come, let us reason together.

4 And they reasoned that if light were Particle, then its speed in water must exceed that in air; but if light be Wave, then its speed in water must diminish from that in air.

5 But for five score years was no one found who could carry forth the crucial experiment. And there was great weeping and lamentation.

6 And it came to pass, that the fame of Newton caused the Light as Particle doctrine to hold sway in the hearts of men.

CHAPTER 5

1 In the fullness of time, there arose another prophet in the Land of England, Thomas Young.

2 And being filled with the spirit of wisdom, Young demonstrated the interference of light from two coherent point sources. Saith Young, He who hath an eye to see, let him see.

3 And the physicists were amazed, saying, Brothers and sisters, how can this be? For behold, upon adding light to light there cometh forth not only regions of more light, but regions of darkness also.

4 Saith Young, Wave functions, shewing positive and negative signs, couldst produce such interference, while particles could not.

5 And Young beheld also the diffraction of light.

6 And there was in the next country Augustin Fresnel, abiding in his laboratory, doing cunning experiments of interference and diffraction,

7 And reasoning as though Light were Wave, did build a mathematical analysis thereon.

8 And Fresnel prophesied the diffraction patterns that would be wrought by divers apertures.

9 And some, such as Poisson, did murmur and complain. Saith Poisson, Fresnel speaketh folly, for behold, if his mathematical reasoning be correct, then a disc, when placed in the light, will shew on the far side a bright spot in the centre of geometrical shadow. How can light shine in the midst of darkness?

10 Then was the experiment performed, and lo! the very spot that Poisson prophesied, based upon Fresnel's mathematics, did shew itself. And Poisson did eat crow.

11 And the measurements of interference maxima and minima, with the calculations of Fresnel, shewed the wavelength of light to be exceedingly small.

12 Then did the physicists know why Newton looked for diffraction but with his resolution saw it not.

13 And in those days also Jean Foucault did measure the speed of light in water, and he saith, Come, ye seekers after truth. Rejoice with me, for lo I have found the speed of light in water to be less than the speed of light in air.

14 Then did the doctrine of Light as Wave wax stronger and stronger, and the doctrine of Light as Particle wax weaker and weaker.

15 And as these things occurred, Michael Faraday with many signs and wonders did link electricity to magnetism in divers demonstrations with moving magnets.

16 Seeing these things, James Clerk Maxwell ascended the high and holy mount of differential equations.

17 And when he descended, Maxwell saith, I have been to the Holy Mountain and have seen a great sight. Hear ye the Laws of the Lord:

18 And God said,
 $\nabla \cdot \mathbf{E} = \mathbf{r}/\hat{\mathbf{I}}_o$
 $\nabla \cdot \mathbf{B} = 0$
 $\nabla \times \mathbf{B} = m_o \mathbf{j} + m_o \hat{\mathbf{I}}_o \int \mathbf{E}/\int t$
 $\nabla \times \mathbf{E} = \mathcal{Z} \int \mathbf{B}/\int t$
 and there was light.

19 For behold, Maxwell saith, see how upon combining these four Laws into two, a pair of Wave Equations results, whose speed is that of light.

20 Surely, saith Maxwell, Light is a Wave in the Electromagnetic Field.

21 Then saith Heinrich Hertz, If Maxwell speaketh the truth, then can light be radiated artificially. And Hertz performed experiments to produce radio waves as Maxwell had prophesied.

22 And lo, Hertz found the waves as Maxwell had taught.

23 And the people rejoiced greatly, and said, Now we have learned Nature's secret, and have found the answer to the question, What Is Light.

CHAPTER 6

1 But it came to pass that Hertz' experiments shewed also deep mysteries,

2 For a strange current appeareth in certain electrical components when light of sufficiently great frequency shineth thereon.

3 But no current appeareth, even with light of great intensity, when the frequency falleth below threshold.

4 Alas, the teachings of Maxwell were sorely inadequate to explain this wonder, which was called the Photoelectric Effect.

5 And the Photoelectric Effect remained a mystery for that generation.

6 And in those days also did Michelson and Morley seek to measure the speed of light relative to the ether,

7 Saying, Alas, we are undone, for the speed of light appeareth to be an invariant. What then shall become of the relativity of Newton, for it is written, Space and Time are taken to be absolute, whence is the speed of light made relative.

8 Then came forth Einstein, who saith, Forsake ye the false doctrine of the ether. Nature hath shewn ye that light is invariant. Behold how space and time are relative.

9 And Einstein continued, and saith, Behold, if ye imagine also light to be Particle, then the Photoelectric Effect maketh sense as a collision between the light particle and the electron. And it was so.

10 But Einstein's prophecy did bring into the teachings of physics another fundamental constant.

11 And lo, this constant hath the same value as the constant earlier introduced by Max Planck, to explain the thermodynamics of light.

12 For Planck had seen a great vision. Should vibrating particles radiate light energy in quanta, then would the thermodynamics of light be healed of its ultraviolet catastrophe.

13 But others, mocking, said unto Planck, Thou hath solved one riddle but hath introduced another.

14 But when Einstein's constant was seen to be Planck's constant and no other, then were the people filled with wonder, and the physicists entered the new covenant of Quantum Mechanics.

CHAPTER 7

1 And there were in the same countries other physicists keeping watch over other problems of physics.

2 In earlier days William Crookes wrought the electrified vacuum

tube and discovered cathode rays.

3 And J.J. Thompson did measure the charge-to-mass ratio of the cathode rays, and beheld the electron.

4 And the physicists said, Behold, here at last is a true particle: a point mass without size or shape, which moveth according to the Laws of Motion as given us by Newton.

5 Then spake a lad called Louis deBroglie. And deBroglie saith, If Light be dually Wave and Particle, then might electrons be dually Particle and Wave?

6 deBroglie was rebuked by his elders, but Einstein saith, Peace, be still, his idea hath merit.

7 Then did Davidson and Germer seek interference among these matter waves as deBroglie had prophesied, and lo! they beheld thin film interference, in crystalline planes of nickel atoms radiated with electron beams.

8 And thus did the physicists behold the Electron as Wave.

9 And a mighty host, among them Bohr, Born, Pauli, Heisenberg, Schrödinger, and Dirac, taught the new doctrine of Quantum Mechanics,

10 And seeing the multitudes, they went up into a mountain: and when they were set, their disciples came unto them:

11 And they opened their mouths and taught them, saying,

12 Blessed are they who learn of physics in both images, Particle and Wave,

13 For the intensity of the matter wave function measureth the probability density of locating the particle.

14 Blessed are they who know the Hamiltonian of the particle, yea also its perturbations,

15 Blessed are they who compute the stationary state wave functions, and the rates of transition between them.

16 Rejoice, and be exceeding glad, for great is your reward in *The Physical Review*.

17 But early attempts to reconcile quantum theory with the electrodynamics of Maxwell and with the relativistic corpuscles of Einstein were afflicted by the demon of infinities.

18 After many tribulations was the demon cast out, and the teachings of Maxwell and Einstein reconciled by Feynman, Schwinger, Dyson, and Tomonaga, who bringeth the glad tidings of Quantum Electrodynamics,

19 Saying, In the beginning the Spirit of Local Gauge Invariance created a massless, spin-one gauge boson that coupleth to electric charge, and lo, there was light.

20 Go ye into all the world, making disciples of renormalizable quantum field theories. Say to all ye meet, O ye of little faith, see now the glory of the cancellation of infinities.

21 And amid great rejoicing did their teachings inspire theories of local gauge invariance for all the elementary particle interactions.

CHAPTER 8

1 But with the doctrine of Quantum Mechanics did the physicists find themselves Philosophers once again. The simple questions, What is Light? and What are Electrons? have no simple answers.

2 To ask, Doth light consist of waves, or doth light consist of particles, is the wrong question indeed.

3 Likewise, when thou asketh, Doth an electron beam consist of particles, or doth it consist of waves, thou doth see through the glass darkly.

4 Then did the physicists realize the difference between seeking Truth, and finding Knowledge.

5 Saith the physicists, we know not what light and electrons truly are, but in a given situation we knoweth well enough what they are like.

6 Particles and waves are not ultimate reality in themselves, but conceptual and orthogonal models thereof. To a good approximation only doth the light and the electron behave as these models say.

7 To every thing there is a season:
A time for light to be like waves,
And a time for light to be like particles;
A time for electrons to be as particles;
And a time for electrons to be as waves.

8 But their ultimate reality eludeth our grasp. No one hath yet invented the concepts in terms of which these riddles become simple.

9 For it is written, Nature continually sheweth herself to be more wondrous than our minds conceive, yea, greater indeed than our minds can conceive.

10 Then spake Neils Bohr, who saith: Hearken ye unto my voice. Blessed are they who behold two kinds of Truth: the Simple Truth, and the Profound Truth.

11 Ye expected to find a Simple Truth, where the opposite of the true statement must be false. But this ye found not.

12 Ye have discovered instead a Profound Truth, where the opposite of the true statement is also true.

13 Behold ye how Nature is filled with Profound Truths.

14 And there are also many other things the physicists did, the which, if they should be written every one, even the world itself could not contain the books that should be written. Amen.

COMMENTARY

Much of the history of how we conceptualize light is familiar to readers of modern physics textbooks. See also W.P.D. Wightman, *The Growth of Scientific Ideas*, Yale University Press, 1953. Historical books and events that are part of the story told here include the following:

Robert Hooke, *Micrographia*, 1664;

The Jesuit monk, Father Francesco Maria Grimaldi, in 1665, first documented an observation of diffraction and coined that name;

Roemer measured the speed of light in 1675, and obtained about two-thirds its modern value;

Christian Huygens, *Traité le la Lumière*, 1690;

Isaac Newton, *Optiks*, 1704;

Leonhard Euler, *New Theory of Light and Color*, 1746;

Jean Foucault measured the speed of light in water in 1850, and obtained about $\frac{3}{4}c$;

The thought of nature being stranger than we *can* suppose was articulated in famous lines by the biologist J.B.S. Haldane.

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