# Chapter 1 The Length Vector Effect

***From the Constancy of the Speed of Light to Motion-Induced Spatial Anisotropy***

The first objects of physics are not a priori pictures of the world but rigorously defined measurable quantities. However grand or elegant its mathematics, every physical theory must ultimately return to the criteria of measurability established by metrology: which fundamental quantities can be operationally defined, which derived quantities can be measured reproducibly, and whether quantitative relations among these quantities remain consistently calibrated across experimental apparatuses and reference frames. Whenever the core concepts of a theory lack clear measurement definitions, or its deductions violate consistency in measuring the same physical quantity, the theory must be re-examined in light of the first principles of metrology.

For precisely this reason, the logical starting point of Anisotropic Spatial Dynamics (ASD) in this monograph is metrology, rather than an a priori philosophy of spacetime or an abstract symmetry of coordinate transformations. All quantitative laws of modern physics ultimately rest on the definitions of fundamental or derived quantities such as length, time, mass, electric charge, frequency, energy, and momentum. At the most basic level lie the metrological definitions of length and time and their kinematic coupling. Unless the measurement relations among propagation, cycle counting, characteristic speed, and spatial distance are clarified, higher-level equations for momentum, energy, field strength, and interactions lack a secure metrological foundation.

ASD therefore begins this monograph with four metrological questions that go directly to the foundations of physics: What is the measurable nature of length? What is the metrological nature of time? Is the wavelength of light a length quantity in the strict sense? How can spatial distance be defined unambiguously during motion and propagation? Rigorous answers to these four questions directly determine the kinematic and dynamic structure underlying the whole edifice of physics.

The first binding axiom that metrology imposes on theoretical physics is the principle of one quantity, one rule (the no-double-standard principle): quantities with the same physical dimension and measurement definition must obey exactly the same transformation law in every experimental configuration and theoretical derivation. Conflicting standards must never be assigned to them in different contexts. If a theory accepts that a light wavelength is a length for metrological purposes but exempts wavelength from the transformation laws governing ordinary geometric lengths in its derivation of Doppler shifts or interference, or reduces wavelength change to a merely secondary consequence of “time dilation,” then at the most fundamental level it applies a double definition to length.

The central theoretical position of ASD is unequivocal: wavelength is length, effective optical path is length, and geometric size is length. Since modern metrology establishes all three through the same optical propagation and cycle-counting processes, they must obey the same directional law of length transformation in a moving spatial system. This chapter sets out to demonstrate rigorously that consistently enforcing this metrological requirement leads, from the constancy of the speed of light in vacuum, not to a presupposed “isotropy of four-dimensional spacetime,” but to the Length Vector Effect (LVE) and the anisotropy of space under motion.

## I. Definitions of Physical Quantities and the Modern Metrological Paradigm

The definition of the value of a physical quantity is the true foundation of physics. Its historical development reflects a profound revolution in how humanity understands natural laws, from macroscopic sensory intuition to microscopic universal constants. The central role of quantity definitions in physics has four aspects:

(1) A common basis for scientific description. Measurement assigns a numerical value by comparing the measurand with an agreed unit. Only strictly unified definitions make data from different locations, times, and laboratories objectively comparable.

(2) The foundation of precision tests. The definition and reproducibility of fundamental units directly determine the resolution achievable when measuring fundamental constants and testing physical laws.

(3) A bridge to quantitative knowledge of nature. Definitions of physical quantities turn qualitative phenomena into mathematical concepts that can be manipulated and falsified, thereby providing an operational framework for describing the physical world.

(4) The basis for the closure of physical laws. Every dynamical equation and conservation law rests on precise definitions of fundamental and derived dimensions. A paradigm shift in the definitions of basic quantities necessarily prompts reconstruction of the physical theories built upon them.

The definition of fundamental units has undergone a fundamental paradigm shift, from dependence on macroscopic material prototypes to anchoring units in fundamental constants of nature. The 1875 Metre Convention established a prototype-based system centred on the platinum–iridium international prototype metre [1]. With advances in precision interferometry, the 11th General Conference on Weights and Measures (CGPM) replaced the physical metre prototype in 1960 with a definition based on the vacuum wavelength of a specified krypton-86 atomic transition [2]. For the first time, the international measurement system explicitly recognized that optical wavelength and macroscopic length belong to the same category of length quantities. In 1983, the 17th CGPM adopted the present definition of the metre: “The metre is the length of the path travelled by light in vacuum during a time interval of 1/299792458 of a second” [3]. Under the major revision of the International System of Units (SI) that took effect on 20 May 2019, the kilogram, ampere, kelvin, and mole were likewise defined through fixed values of the Planck constant $h$, elementary charge $e$, Boltzmann constant $k$, and Avogadro constant $N_A$ [4]. This historical transformation completed modern metrology's transition from “defining units by artefacts and then measuring natural constants” to “defining units by natural constants and realizing their values through physical processes.”

This metrological paradigm has three far-reaching physical implications. First, measurement is freed from the assumption of a rigid material standard: the metre no longer depends on a macroscopic solid ruler susceptible to temperature, stress, and mechanical deformation, but is anchored directly to the vacuum speed-of-light constant $c$. Second, unit realization is universally reproducible: any laboratory equipped with sufficiently accurate time–frequency standards can realize a high-precision length standard independently and locally. Third, length is inseparable from directed optical propagation: in modern metrology, length is no longer an abstract Euclidean-geometric label divorced from physical processes, but a dynamic process quantity jointly specified by the optical propagation speed $c$ and the process duration $t$. It is from this primary metrological fact that the chapter constructs a theory of length measurement under motion.

## II. The Length Vector Effect and Spatial Anisotropy

The classical intuition of “length” arose from static comparison using rigid material rulers: in Euclidean geometry, length is regarded as a scalar independent of direction. Once the length standard is upgraded from a material ruler to an “optical ruler,” however—that is, once length is defined by the product of the vacuum light-speed constant $c$ and the light-propagation time $t$—a fundamental dynamical fact becomes apparent: photon propagation has an inherent spatial direction, and an effective length calculated from directed optical propagation necessarily carries directional information. Although Lorentz (1904) [5] and Einstein (1905) [6] likewise began with the constancy of the speed of light, the introduction of a priori spatial isotropy and coordinate transformations in four-dimensional Minkowski spacetime restricted motion effects to “longitudinal Lorentz contraction” and “the slowing of moving clocks,” while prescribing unchanged transverse lengths. ASD instead follows the metrological nature of defining length by optical

propagation: because every operational length measurement entails a photon's directed flight along a specific spatial direction $\hat{n}$, a length measured under motion must exhibit a vector response dependent on the angle $\phi$ between the measurement and motion directions.

In ASD, a "length vector" is not simply an ordinary geometric distance rewritten as a three-dimensional Euclidean displacement vector. Rather, it characterizes precisely the constitutive dependence of a length measurement on the propagation direction. Let the scalar magnitude $r$ denote the measured effective length, let the unit vector $\hat{n}$ specify the spatial direction of photon propagation or the measurement path, and let the directed length vector be $\vec{r} = r\hat{n}$. Under motion, along a selected measurement direction $\hat{n}$, the effective length $r'$ measured is a function of the directional angle $\phi$.

Under the metrological rule defining length by the speed of light in vacuum, a photon is emitted from one end of the object and its propagation time $t$ to the other end is measured. The scalar length of the object is then uniquely given by Eq. (1.1):

$$r = c \cdot t \tag{1.1}$$

Equation (1.1) provides the basic measurement model for the speed-of-light definition of length, where $r$ is the length being measured, $c$ is the defined vacuum speed of light, and $t$ is the time required for the photon to traverse the full path. For a measured segment with endpoints A and B, two directed measurement processes exist: forward (a photon emitted from A toward B) and reverse (from B toward A). Introducing the directed light-velocity vector $\vec{c} = c\hat{n}$, the directed length vector can be expressed exactly as:

$$\vec{r} = \vec{c} \cdot t \tag{1.2}$$

In Eqs. (1.1) and (1.2), the length-measurement standard consists jointly of the vacuum speed-of-light constant $c$ and a standard clock. If the photon transit times $t$ and $t'$ measured for the same object in different states of motion differ, metrology must distinguish strictly whether the difference originates from a change in the rate of the clock standard or from a genuine change in the object's true effective length in the moving spatial system.

Consider two ideal comparative measurements. (1) Both the observer and the object AB are stationary; a photon travels from one end to the other, and the stationary standard clock records a transit time $t$. (2) The observer and standard clock remain at rest under exactly the same environmental conditions, but object AB moves uniformly in a straight line at velocity $\vec{v}$; the measured photon transit time is $t'$. Since the observer's clock remains at rest in the same physical environment in both measurements, its intrinsic oscillation frequency and timekeeping properties undergo no physical change. Therefore $t' \neq t$ is not evidence that the clock standard has become inaccurate or that "time dilation" has occurred; it directly demonstrates, in the ASD interpretation, that motion changes the true effective length of the measured object in space.

Furthermore, under the relativity of motion, whether an object is described as "stationary" or "in uniform motion" depends on the choice of reference frame, whereas the intrinsic counting rate of a calibrated standard clock is a physical property that does not change simply because an observer chooses a different frame. Thus, observers O and O′, moving uniformly relative to one another, record the time variables $t$ and $t'$, respectively. These variables have fully equivalent metrological status. Neither clock intrinsically "runs faster" or "runs slower"; the difference between $t$ and $t'$ directly corresponds to a difference between the effective optical-path lengths in the two frames. We now derive the quantitative transformations between $t$ and $t'$, and between $r$ and $r'$.

Let observer O be at rest in coordinate system $K$ and record time $t$ with a standard clock; let observer O′ be at rest in system $K'$ and record time $t'$ with an identical, synchronously calibrated standard clock.

Consider the measured object OA. At the initial instant $t = t' = 0$, the origins of $K$ and $K'$ coincide with endpoint O of the object. The position vectors of its other endpoint A in systems $K$ and $K'$ are respectively $\vec{r}$ and $\vec{r}'$:

$$\vec{r} = x\mathbf{i} + y\mathbf{j} + z\mathbf{k} \tag{1.3}$$

$$\vec{r}' = x'\mathbf{i} + y'\mathbf{j} + z'\mathbf{k} \tag{1.4}$$

At the initial instant, a photon is emitted from endpoint O along the measured object. Observers O and O′ record the photon reaching endpoint A after transit times $t$ and $t'$, respectively. The directed length vectors of object OA measured in the two coordinate systems are therefore:

$$\vec{r} = \vec{c} \cdot t \tag{1.5}$$

$$\vec{r}' = \vec{c} \cdot t' \tag{1.6}$$

In the first relative-motion configuration, let system $K'$ (observer O′) move uniformly relative to the stationary object OA (system $K$) with velocity $\vec{v}$. The directed length vectors then satisfy the linear transformation:

$$\vec{r}' = \gamma(\vec{r} - \vec{v}t) \tag{1.7}$$

Here $\gamma$ is a dimensionless scale-transformation factor determined by the constancy of the vacuum speed of light, and $\vec{v}$ is the velocity vector of observer O′ relative to system $K$:

$$\vec{v} = v_x\mathbf{i} + v_y\mathbf{j} + v_z\mathbf{k} \tag{1.8}$$

In the reciprocal motion configuration, system $K$ (observer O) moves uniformly relative to system $K'$ at velocity $-\vec{v}$. Symmetric reciprocity gives the inverse transformation:

$$\vec{r} = \gamma(\vec{r}' + \vec{v}t') \tag{1.9}$$

To determine the universal transformation factor for a given speed $v$, denoted $\gamma$, consider the reference case in which a photon is emitted collinearly with the motion axis ($\vec{c} \parallel \vec{v}$). Take the vector inner product of both sides of Eqs. (1.7) and (1.9):

$$\vec{r}' \cdot \vec{r} = \gamma^2(\vec{r} - \vec{v}t) \cdot (\vec{r}' + \vec{v}t')$$

Substituting Eqs. (1.5) and (1.6) and expanding the inner product, the cross terms $\vec{c} \cdot \vec{v}tt'$ and $-\vec{v} \cdot \vec{c}tt'$ cancel exactly:

$$c^2tt' = \gamma^2(c^2tt' + \vec{c} \cdot \vec{v}tt' - \vec{v} \cdot \vec{c}tt' - v^2tt')$$

Cancelling the nonzero common factor $tt'$ and choosing the positive root gives the exact transformation factor:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.10}$$

Substitution of Eqs. (1.5), (1.6), and (1.10) into Eq. (1.7) yields the vector transformation equation satisfied by optical propagation in an arbitrary direction:

$$\vec{r}' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}(\vec{c} \cdot t - \vec{v}t) \tag{1.11}$$

It is important to note that Eq. (1.11) describes a vector relation between directed optical paths. Because an actual length measurement is made along the unit vector $\hat{n} = \vec{c}/c$ in the direction of light propagation, the effective optical-path length $r' = ct'$ is uniquely determined by the projection of vector $\vec{r}'$ onto

measurement direction $\hat{n}$, namely $\vec{r}' \cdot \hat{n}$. Let velocity $\vec{v}$ and measurement-direction unit vector $\hat{n}$ subtend angle $\phi$. The projection of velocity onto that direction is:

$$\vec{v} \cdot \hat{n} = v\cos\phi$$

Taking the inner product of both sides of Eq. (1.11) with the unit vector $\hat{n}$, the effective optical path along direction $\hat{n}$ satisfies exactly:

$$ct' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}(ct - vt\cos\phi)$$

Dividing both sides by the vacuum speed of light $c$ gives the directional transformation of photon transit time under motion, Eq. (1.12):

$$t' = t \cdot \frac{1-\frac{v}{c}\cos\phi}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.12}$$

Here the directional angle $\phi$ is the angle between the velocity vector $\vec{v}$ and the light-propagation (length-measurement) unit vector $\hat{n}$. Multiplying both sides of Eq. (1.12) by the vacuum speed of light $c$ gives the central kinematic theorem of ASD—the Length Vector Effect (LVE):

$$r' = r \cdot \frac{1-\frac{v}{c}\cos\phi}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.13}$$

In these expressions, $r'$ and $r$ denote the effective lengths measured, respectively, by an observer moving uniformly at velocity $v$ relative to the object $\mathrm{OA}$ (observer $\mathrm{O}'$), and by an observer at rest relative to the object (observer $\mathrm{O}$), along direction $\phi$. When the relative speed $v = 0$, Eq. (1.13) reduces exactly to:

$$r' = r \tag{1.14}$$

Equation (1.14) states that when the measured object is stationary relative to the observer, the measured length is independent of directional angle $\phi$ and space exhibits static isotropy. In the presence of relative motion ($v > 0$), however, the effective length is modulated by the directional factor $\kappa_{\mathrm{LVE}}(v, \phi) = (1 - (v/c)\cos\phi)/\sqrt{1 - v^2/c^2}$, exhibiting pronounced motion-induced spatial anisotropy.

Substituting Eq. (1.10) into Eq. (1.7) directly gives the three-dimensional vector coordinate-transformation equation in the ASD framework. Unlike the standard Lorentz transformation, which prescribes invariant transverse coordinates, this transformation retains the common factor $\gamma$ in its transverse components:

$$\vec{r}' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}(\vec{r} - \vec{v}t) \tag{1.15}$$

Take the relative velocity along the positive $x$ axis, namely $\vec{v} = v_x\mathbf{i}$ ($v_x = v$). The Cartesian components of Eq. (1.15) then become:

$$x' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}(x - vt) \tag{1.16}$$

$$y' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}y \tag{1.17}$$

$$z' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}z \tag{1.18}$$

If the object lies along the $y$ or $z$ axis, so that the measurement direction is orthogonal to the relative motion ($\phi = 90°$, $\cos\phi = 0$), the Length Vector Effect formula (1.13) directly gives the transverse effective length:

$$r' = r \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.19}$$

Equation (1.19) is strictly consistent with the component transformations (1.17) and (1.18), demonstrating that the transverse effective optical path extends with speed by the factor $\gamma = 1/\sqrt{1 - v^2/c^2}$.

Historically, Lorentz proposed physical contraction in the direction of motion in 1904 [5], and Einstein reformulated it in special relativity in 1905 [6] as an effect of coordinate rotation in four-dimensional spacetime, with moving clocks running slower (time dilation), longitudinal scales contracting, and transverse spatial scales unchanged ($y' = y$, $z' = z$). Transverse coordinate invariance is presented here as an a priori requirement for preserving the isotropy of four-dimensional Minkowski spacetime and as the premise for attributing the transverse Doppler effect to "time dilation" in special relativity. ASD takes a different route based on the optical definition of length: a transverse measurement path ($\phi = 90°$) acquires an inclined resultant optical path under relative motion, and its effective length must therefore increase according to Eq. (1.19). In short, the effective length of a stationary object is independent of the measurement direction, whereas that of a moving object varies continuously with angle $\phi$ between the motion and measurement directions (forward compression, backward extension, and transverse extension). This universal law is the Length Vector Effect, expressed in Eqs. (1.12) and (1.13).

At a deeper level, the Length Vector Effect formulas (1.12)–(1.13) are not merely a semantic deduction from existing SI definitions. They arise from a universal law of process metrology: every physical propagation, phase evolution, and measurable process obeys a basic relation between its spatial process scale $S$, its rate of advance $v$, and its process-counting time $t$:

$$S = vt \tag{1.20}$$

Equation (1.20) states that a length quantity is not an a priori Euclidean-geometric label existing outside physical processes; it is the manifestation of the spatial measure of a specific propagation process under a given characteristic-speed constraint. Applying this universal relation to vacuum optical propagation at constant vacuum light speed $c$ yields the modern physical starting point for defining length:

$$r = ct$$

The time variable $t$ here is, metrologically, the accumulated counting scale of a standard periodic process, rather than an abstract entity flowing independently of material motion. In logical priority, the physical relation $r = ct$ under the constancy of the speed of light is the primary physical source, while the 1983 SI definition of the metre is its standardized expression within the modern measurement system. Furthermore, when the time $t$ is one complete renewal period $T$ of a periodic wave source, the distance propagated in one period is the wavelength:

$$\lambda = cT$$

Wavelength is therefore a specific realization of a length quantity under one-period phase renewal. Geometric length, propagated optical path, and optical wavelength have a common metrological origin and must obey the same directional transformation law. This is the dividing line ASD draws between itself and special relativity: ASD contends that special relativity obtains isotropic four-dimensional Lorentz transformations by introducing a priori "spatial isotropy" in addition to the "constancy of the speed of light." Once one returns rigorously to the directed measurement logic of $r = ct$, the constancy of the speed of light does not automatically imply equality of effective lengths in all directions. Instead, applying $r = ct$ and $\lambda = cT$ consistently to measurements under motion yields the Length Vector Effect, with forward compression ($\phi = 0°$), backward extension ($\phi = 180°$), and transverse extension ($\phi = 90°$), providing a

unified kinematic basis for the classical optical experiments, gravitational effects, relativistic dynamics, and matter-wave theory discussed in later chapters.

# III. A Unified Explanation of Classical Physics Experiments from the Length Vector Effect

On the basis of Eqs. (1.12) and (1.13), ASD interprets optical Doppler shifts, the Michelson–Morley experiment, the Hoek experiment, the Fizeau flowing-water experiment, the Sagnac effect, high-speed particle lifetimes, and moving atomic clocks as direct consequences of directional changes in effective spatial length under motion, and derives a unified mathematical account without introducing "time dilation" or an "ether-drag coefficient."

## 1. Optical Doppler Shift

In 1842, Doppler predicted that the relative motion of a wave source and an observer would produce a frequency shift [7]; Fizeau verified the phenomenon in acoustic experiments in 1848 [8]. In 1905, Einstein derived the relativistic Doppler-shift formula from the Lorentz transformation [6], predicting a nonzero redshift even when the light source moves perpendicular to the line of sight ($\phi = 90°$)—the transverse Doppler effect. This effect was first confirmed in 1938 by Ives and Stilwell using canal rays [9]. In special relativity, the transverse Doppler shift is interpreted as direct evidence of "internal time dilation" in a moving source, while the wavelength change is treated merely as a consequence of the frequency change.

ASD proposes an entirely different physical mechanism: the light wavelength λ is itself a spatial length in the strict sense, namely the distance advanced by the wave during one intrinsic oscillation period. When the light source moves relative to the observer, neither the standard clock nor the speed-of-light constant changes. Wavelength, as a length quantity, must therefore directly obey the Length Vector Effect of Eq. (1.13); the observed optical Doppler shift, including the transverse Doppler redshift, is attributed entirely to the directional vector variation of wavelength.

Consider a point light source at the centre of a stationary sphere whose rest radius $r$ is exactly equal to the source's intrinsic wavelength $\lambda$ at rest. Expressing wavelength as a directed length vector, the stationary state gives:

$$\vec{\lambda} = \vec{r} \tag{1.21}$$

When the source moves uniformly in a straight line at speed $v$ relative to the observer, Eq. (1.13) specifies that, at directional angle $\phi$, the moving wavelength $\lambda'$ satisfies exactly:

$$\lambda' = \lambda \cdot \frac{1-\frac{v}{c}\cos\phi}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.22}$$

By the constancy of the speed of light in vacuum, wavelength and frequency in the stationary and moving states both satisfy:

$$\lambda' \cdot f' = \lambda \cdot f = c \tag{1.23}$$

Here $f$ and $f'$ are the frequencies measured for the source at rest and in motion, respectively. Substituting Eq. (1.23) into Eq. (1.22) immediately yields:

$$f = f' \cdot \frac{1-\frac{v}{c}\cos\phi}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.24}$$

Solving for the observed frequency $f^{'}$ of the moving source gives the exact optical Doppler-shift formula:

$$f^{'} = f \cdot \frac{\sqrt{1-\frac{v^2}{c^2}}}{1-\frac{v}{c}\cos\phi} \tag{1.25}$$

Equations (1.22)–(1.25) demonstrate that, when $\phi = 90°$, the transverse effective wavelength is extended according to $\lambda^{'} = \lambda/\sqrt{1 - v^2/c^2}$ and, at constant light speed $c$, directly yields the transverse Doppler redshift $f^{'} = f\sqrt{1 - v^2/c^2}$. In this account, the optical Doppler shift is wholly a geometric manifestation of wavelength obeying the Length Vector Effect as a length quantity, with no need to assume "expansion of an independent time dimension."

## 2. The Michelson–Morley Experiment

In 1887, Michelson and Morley used an interferometer with two orthogonal arms to search for differences in light speed due to Earth's motion relative to the hypothetical "ether." They obtained the celebrated "null result": rotation of the interferometer did not produce the anticipated fringe displacement [10]. To explain this result, FitzGerald (1889) [11] and Lorentz (1892) [12] proposed physical length contraction in the direction of motion. Einstein (1905) [6] instead incorporated the effect into the coordinate description of four-dimensional Minkowski spacetime through Lorentz contraction (longitudinal contraction without a corresponding change in transverse length).

Within the ASD framework, the Michelson–Morley null result receives a more symmetric metrological explanation: both the longitudinal and transverse interferometer arms obey the same Length Vector Effect law (1.13) in moving space. The equality of their round-trip optical transit times is attributed not to "longitudinal contraction with transverse invariance," but to the fact that the arithmetic sum of forward compression ($\phi = 0°$) and backward extension ($\phi = 180°$) is exactly twice the transverse extension ($\phi = 90°$). This provides exact mathematical closure of the Length Vector Effect across the two orthogonal arms.

Suppose that, when the interferometer is at rest, both its longitudinal and transverse arms have intrinsic length $L$. Let $c$ be the vacuum light speed and $v$ the apparatus speed. Equation (1.12) gives the round-trip transit times of the two arms as follows:

For the longitudinal arm (parallel to the motion, with outward trip $\phi = 0°$ and return trip $\phi = 180°$):

(1) On the outward trip (along the direction of motion, $\phi = 0°$), the photon transit time is:

$$t_1^{'} = \frac{L}{c} \cdot \frac{1-\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.26}$$

(2) On the return trip (opposite to the motion, $\phi = 180°$), the photon transit time is:

$$t_2^{'} = \frac{L}{c} \cdot \frac{1+\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.27}$$

(3) The total round-trip time $T_{\text{long}}$ of the longitudinal arm is:

$$T_{\text{long}} = t_1^{'} + t_2^{'} = \frac{L}{c} \cdot \frac{1-\frac{v}{c}+1+\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{2L}{c} \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.28}$$

For the transverse arm (perpendicular to the direction of motion, $\phi = 90°$), Eq. (1.12) gives the one-way photon transit time:

$$t_{\text{trans}}^{'} = \frac{L}{c} \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.29}$$

The total round-trip time $T_{\text{trans}}$ of the transverse arm is:

$$T_{\text{trans}} = 2 \cdot t'_{\text{trans}} = \frac{2L}{c} \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.30}$$

Comparing Eqs. (1.28) and (1.30) immediately gives the exact identity $T_{\text{long}} = T_{\text{trans}}$. For an interferometer arm oriented at any angle $\phi$, the outward path ($\phi$) and return path ($\phi + 180°$) have direction-odd terms containing $\cos\phi$ that cancel exactly. The total round-trip time is always $(2L/c)/\sqrt{1 - v^2/c^2}$, entirely independent of orientation angle $\phi$. Thus, the model predicts zero fringe displacement under arbitrary rotation of the interferometer.

The core differences between the ASD and special-relativistic explanations of the Michelson–Morley experiment are summarized in the following table:

| Aspect | Special Relativity (SR) | Anisotropic Spatial Dynamics (ASD) |
|---|---|---|
| Physical premises | Constant light speed, the relativity principle, and Lorentz transformations | Constant light speed, metrological definitions, and directional properties of length |
| Origin of the null result | Length contraction and the time structure under Lorentz transformations | Longitudinal and transverse optical paths obey the same length-vector factor |

The preceding derivation shows, within the ASD formulation, that the Michelson–Morley null result follows mathematically from the round-trip closure of longitudinal and transverse directed optical paths under the same length-vector factor. The round-trip photon propagation time represents the total effective round-trip optical-path length, rather than an expansion or contraction of a "time dimension."

## 3. The Hoek Experiment

In 1818, Fresnel proposed that a moving medium partially drags light waves to explain Arago's experiment on stellar refraction. The proposed drag coefficient was $f = 1 - 1/n^2$, where $n$ is the refractive index of the medium [13]. In 1868, the Dutch physicist Hoek devised an asymmetric medium-interferometry experiment [14]: one interferometer path passed through a stationary water column of geometric length $L$ and refractive index $n$, while the other passed through vacuum (or air). The arms were adjusted to form stable interference fringes when stationary. When the apparatus moved with Earth at speed $v$ or was rotated by $180°$, the experiment again exhibited a null fringe shift. In special relativity, this result is explained by the cancellation produced when the Lorentz velocity-addition law reduces to the Fresnel drag coefficient at low speeds.

ASD argues that neither an "ether dragged by a medium" nor an additional relativistic velocity-composition hypothesis is needed: a transparent medium of refractive index $n$ establishes an equivalent optical length $L_{\text{opt}} = nL$. When the entire apparatus moves at velocity $v$, the medium segment's effective optical path, being a spatial length, obeys exactly the same Length Vector Effect (1.13) as the vacuum segment. The closed round-trip paths therefore retain zero optical-path difference.

In the stationary reference frame, a medium-filled tube of geometric length $L$ and refractive index $n$ has the following equivalent optical-path length at rest:

$$L_{\text{opt}} = n \cdot L \tag{1.31}$$

When the entire interferometer moves with velocity $v$, Eq. (1.13) gives the true effective moving optical path at angle $\phi$, namely $L'_{\text{opt}}$, as:

$$L'_{\text{opt}} = nL \cdot \frac{1-\frac{v}{c}\cos\phi}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.32}$$

For the medium-filled arm parallel to the direction of motion, the photon transit times on the outward and return trips are respectively:

(1) Outward trip ($\phi = 0°$):

$$t_1^{'} = \frac{nL}{c} \cdot \frac{1-\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.33}$$

(2) Return trip ($\phi = 180°$):

$$t_2^{'} = \frac{nL}{c} \cdot \frac{1+\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.34}$$

The total round-trip time $T^{'}$ in the medium-filled arm is:

$$T^{'} = t_1^{'} + t_2^{'} = \frac{2nL}{c} \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.35}$$

Compare the round-trip propagation times of the vacuum arm ($n = 1$) and the medium-filled arm ($n > 1$):

$$T_{\text{vac}}^{'} = \frac{2L_{\text{vac}}}{c} \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$T_{\text{med}}^{'} = \frac{2nL_{\text{med}}}{c} \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

It follows directly that, if the two arms are calibrated at rest to satisfy equal optical paths ($L_{\text{vac}} = nL_{\text{med}}$), the round-trip factor $1/\sqrt{1 - v^2/c^2}$ from the Length Vector Effect is universal for vacuum and refractive media alike. At any apparatus velocity $v$, the equality $T_{\text{vac}}^{'} = T_{\text{med}}^{'}$ therefore holds. This derivation brings vacuum and medium-filled paths under a single vector transformation law for effective optical path, without invoking an ad hoc "Fresnel ether-drag coefficient."

## 4. The Fizeau Flowing-Water Experiment

In 1851, Fizeau performed his celebrated flowing-water interference experiment [15]. Two coherent beams passed through moving water columns in the downstream and upstream directions, with water speed $v$, and a significant fringe shift was measured. In conventional theory and special relativity, the Fizeau result is described in terms of partial ether dragging or the first-order approximation to the relativistic velocity-addition formula $(c/n \pm v)/(1 \pm v/(nc))$.

In the ASD framework, the physical picture of the Fizeau experiment is direct: when the water column flows at velocity $v$ relative to a laboratory observer at rest, the downstream and upstream beams correspond to opposite directional angles ($\phi = 180°$ and $\phi = 0°$) in the Length Vector Effect formula (1.13). The resulting effective optical paths acquire antisymmetric directional distortions. The exact difference between the transit times of the two counterpropagating beams through flowing water is, in this account, another direct instance of Eq. (1.38), the same formula used for the Sagnac time difference of a rotating-ring interferometer in the next subsection.

## 5. Circumference of a Rotating Ring and the Sagnac Effect

In 1913, Sagnac split a light beam into clockwise and counterclockwise components and recombined them after each had traversed a closed circular optical path in opposite directions. When the ring interferometer rotated uniformly at angular velocity $\omega$, a fringe shift proportional to both angular velocity and enclosed area was observed [16]. In relativistic descriptions, the rotating ring is a non-inertial system; standard treatments involve metric cross terms in general relativity, anisotropic coordinate light speeds in rotating frames, or conventions of nonglobal simultaneity.

ASD offers a direct derivation of the Sagnac effect without invoking general relativity or a non-inertial coordinate light-speed hypothesis. The rotating ring is divided into infinitesimal arc elements undergoing tangential motion at linear speed $v$. Light travelling with and against the rotation corresponds to different angles $\phi$ relative to the ring's tangential motion, and hence to different true closed effective optical-path lengths. The same directional time-difference formula (1.38) thereby unifies the Sagnac effect with the Fizeau flowing-water experiment.

Let the stationary radius of the ring be $R$ and the time required for light to make one circuit of the stationary ring be $t$. When the ring rotates uniformly with angular velocity $\omega$ and tangential linear speed $v$, divide its circumference into infinitesimal arc elements and apply Eq. (1.12) to each element. In Eq. (1.12), velocity $\vec{v}$ is defined as the observer's velocity relative to the measured medium. Therefore, when the laboratory observer is stationary and the ring medium moves at linear velocity $v$, the relative velocity reverses direction (an angular difference of $180°$). A beam travelling opposite to the ring's rotation corresponds to $\phi = 0°$, with one-circuit time $t'_{逆}$; a beam travelling with the rotation corresponds to $\phi = 180°$, with one-circuit time $t'_{顺}$. Integration around the closed loop immediately gives:

$$t'_{逆} = t \cdot \frac{1-\frac{v}{c}\cos 0°}{\sqrt{1-\frac{v^2}{c^2}}} = t \cdot \frac{1-\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.36}$$

$$t'_{顺} = t \cdot \frac{1-\frac{v}{c}\cos 180°}{\sqrt{1-\frac{v^2}{c^2}}} = t \cdot \frac{1+\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.37}$$

Subtracting Eqs. (1.36) and (1.37) gives the exact time difference between the co-rotating and counter-rotating beams after one circuit:

$$\Delta t = t'_{顺} - t'_{逆} = t \cdot \frac{2\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1.38}$$

Equation (1.38) also gives the exact time difference for counterpropagating beams through the moving-medium section in the Fizeau experiment, where the transit time for a stationary water column is $t = nL/c$, $n$ is the refractive index of water, and $L$ is the channel's geometric length.

For a vacuum (or air) circular optical path of stationary radius $R$, the time for light to travel once around the stationary ring is:

$$t = \frac{2\pi R}{c} \tag{1.39}$$

Let the effective radius of the uniformly rotating ring be $R'$. The magnitude of the tangential linear velocity at its circumference is then:

$$v = R' \cdot \omega \tag{1.40}$$

Because the ring's radial direction is always orthogonal to its tangential velocity ($\phi = 90°$), the transverse length transformation (1.19) implies the exact relation between the effective rotating radius $R'$ and stationary radius $R$:

$$R' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} R \tag{1.41}$$

Substituting Eqs. (1.39), (1.40), and (1.41) into Eq. (1.38) yields:

$$\Delta t = \frac{2\pi R}{c} \cdot \frac{2R'\omega}{c\sqrt{1-\frac{v^2}{c^2}}} = \frac{4\pi\omega R'^2}{c^2} \tag{1.42}$$

Writing the effective area enclosed by the rotating ring as $S^{'} = \pi R_r^2$, we obtain the exact Sagnac time-difference formula:

$$\Delta t = \frac{4\omega S^{'}}{c^2} \tag{1.43}$$

Equations (1.38)–(1.43) show that, in ASD, the Fizeau flowing-water experiment and the Sagnac rotational interference effect have a unified mathematical origin. They are geometric manifestations of the Length Vector Effect in, respectively, optical paths through a translating medium and closed optical paths under rotation.

## 6. Moving-Particle Lifetimes and Clock-Reading Effects

Unstable muons ($\mu$ particles) are produced when high-altitude cosmic rays collide with atmospheric molecules. Their mean lifetime at rest is approximately $2.15 \times 10^{-6}$ s (or about 2.2 μs). Under classical Newtonian kinematics, even at a speed approaching that of light, a $\mu$ particle would travel only about 643 m in one mean lifetime, far less than the characteristic atmospheric thickness ($10 \sim 15$ km). Nevertheless, Rossi and Hall's mountain-altitude measurements in 1941 [17] and the precision experiment by Frisch and Smith in 1963 [18] confirmed that large numbers of $\mu$ particles created high in the atmosphere penetrate to the ground. Special relativity attributes this phenomenon in the terrestrial frame to "time dilation" within the fast-moving particle (an increased lifetime).

Using the fundamental process relation (1.20), ASD provides an explanation without changing the ontology of time. Consider a particle moving at constant velocity $\vec{v} = v\hat{n}$ uniformly from point A to point B. Let its directed path vector between the two points be $\vec{L} = L\hat{n}$ and the duration of the flight be $T$. Then the ratio of projections along the unit direction of motion $\hat{n}$ satisfies exactly:

$$T = \frac{\vec{L}\cdot\hat{n}}{\vec{v}\cdot\hat{n}} = \frac{L}{v} \tag{1.44}$$

Equation (1.44) states that, at a fixed speed $v$, the flight-process reading $T$ is strictly proportional to the spatial path length $L$. According to the forward Length Vector Effect (1.13), taking the direction facing the motion as $\phi = 0°$, the intrinsic measurement distance $L^{'}$ co-moving with the particle and the penetration distance $L$ measured by a stationary observer on Earth satisfy exactly:

$$L^{'} = L \cdot \frac{1-\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}} = L\sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}} \tag{1.45}$$

For a representative atmospheric $\mu$-particle speed of $v = 0.998c$, take the co-moving flight distance corresponding to its intrinsic decay lifetime to be $L^{'} = 643$ m. Substitution into Eq. (1.45) and solving for the atmospheric penetration distance $L$ measured by the stationary terrestrial observer gives the exact radical expression:

$$L = L^{'}\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}} = 643\sqrt{\frac{1+0.998}{1-0.998}}\ \text{m} = 1929\sqrt{111}\ \text{m} \tag{1.46}$$

The penetration distance $1929\sqrt{111}$ m given by Eq. (1.46), numerically about 20323.2 m or more than 20.3 km, greatly exceeds the thickness of the troposphere and the lower stratosphere. Within the ASD framework, this is taken to demonstrate that high-altitude $\mu$ particles can reach the ground not because their internal time flows more slowly, but because high-speed motion strongly compresses the particle's forward effective spatial path by the factor $\sqrt{(1 - v/c)/(1 + v/c)}$.

The same principle can be applied directly to around-the-world atomic-clock comparisons, such as the 1972 Hafele–Keating experiment [19,20]. Consider two identical atomic clocks, synchronously calibrated at the same initial point on the equator. One is carried on an aircraft that makes one uniform-speed

circumnavigation along the equator at relative speed $v$ and returns to its starting point. When considering only the kinematic Length Vector Effect (after separating the correction due to the gravitational-potential difference at altitude, as discussed in Chapter 2), the effective path length $L'$ experienced by the airborne clock and the travel distance $L$ measured from the ground also obey Eq. (1.45). Accordingly, the ratio of the accumulated reading $T'$ of the airborne clock to the accumulated reading $T$ of the terrestrial reference clock is exactly:

$$\frac{T'}{T} = \frac{L'}{L} = \sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}} \tag{1.47}$$

## IV. Fundamental Theoretical Differences Between ASD and Special Relativity

Both ASD and special relativity (SR) accept the constancy of the vacuum speed of light, and both offer quantitative accounts consistent with such principal experimental observations as Doppler shifts, the Michelson–Morley, Hoek, and Fizeau experiments, the Sagnac effect, and the atmospheric penetration of high-altitude $\mu$ particles. Their fundamental difference lies in the underlying physical ontology and metrological geometry. SR attributes these effects to transformations in four-dimensional Minkowski spacetime (time dilation and longitudinal contraction alone), whereas ASD brings them together as vector variations in effective spatial length with the direction of motion under a speed-of-light-based length definition. Their seven central differences are summarized below:

1. Spatial anisotropy and the transverse length transformation. SR prescribes unchanged coordinates transverse to the motion ($y' = y$), with contraction only along the longitudinal direction. ASD instead derives the directional factor $\kappa_{\mathrm{LVE}}(v,\phi) = (1-(v/c)\cos\phi)/\sqrt{1-v^2/c^2}$ from the metrology of directed optical propagation and asserts that the transverse effective length ($\phi = 90°$) is also modified by motion, extending by the factor $\gamma$.

2. The physical meaning of differences in clock readings. SR explains differences in moving-particle lifetimes and moving-clock readings in terms of "dilation of the time dimension itself." ASD maintains that the intrinsic timekeeping properties of a calibrated standard clock do not change merely with the choice of reference frame; differences in readings directly reflect a genuine change in the effective physical path length $L'$ traversed by the particle or apparatus along the direction of motion.

3. The status of wavelength and the origin of the transverse Doppler effect. SR treats frequency as the primary variable and attributes the transverse Doppler shift to time dilation of a moving source. ASD instead establishes the no-double-standard axiom that "wavelength is length," and attributes the transverse Doppler redshift directly to the extension of the transverse effective wavelength $\lambda' = \gamma\lambda$.

4. The closure mechanism of the Michelson–Morley null result. SR relies on longitudinal coordinate contraction to cancel the difference between longitudinal and transverse round-trip optical paths. ASD shows that the sum of longitudinal outward compression ($\phi = 0°$) and return extension ($\phi = 180°$) naturally equals twice the one-way transverse extension ($\phi = 90°$), so that the null result is an intrinsic algebraic closure of one length-vector factor over any round-trip path orientation.

5. The theoretical coherence of rotational interference (the Sagnac effect). A rotating loop cannot be closed using purely inertial-frame transformations within SR; standard treatments employ general-relativistic metrics or nonglobal simultaneity conventions. ASD directly applies the forward and reverse directional difference of Eq. (1.12) to infinitesimal ring elements, obtaining the exact Sagnac formula (1.43) by algebraic integration.

6. Unity of vacuum and refractive media. Conventional theory and SR address optics in moving media using, respectively, the Fresnel drag coefficient or the relativistic velocity-addition law. ASD directly

incorporates the medium's equivalent optical path $L_{\mathrm{opt}} = nL$ into the Length Vector Effect, unifying vacuum and medium-filled optical paths without drag.

7. Logical priority of axioms. SR takes the abstract relativity principle, the invariance of the speed of light, and an a priori isotropy assumption as its axiomatic starting points. ASD instead takes the process-metrology relation $S = vt$ and the speed-of-light definition of length $r = ct$ as primary and argues that the anisotropy of moving space is a direct metrological consequence of constant light speed.

## V. Chapter Summary: Core Propositions, Domain of Validity, and Theoretical Outlook

Starting from the first principles of metrology, this chapter systematically establishes the kinematic foundation of Anisotropic Spatial Dynamics (ASD). Its principal theoretical conclusions can be summarized in three closely connected propositions. (1) The process-metrological nature of length and the no-double-standard axiom: the modern SI defines the metre jointly through the vacuum light-speed constant $c$ and time measurement, turning length measurement from static comparison with a material artefact into the counting of a directed optical propagation process ($r = ct$). Geometric dimensions, effective optical paths, and optical wavelengths ($\lambda = cT$) are all spatial length quantities and must obey the same transformation rule. (2) The Length Vector Effect (LVE) theorem: at relative motion speed $v$, an effective length measured in a direction at angle $\phi$ to the motion satisfies exactly $r' = r(1 - (v/c)\cos\phi)/\sqrt{1 - v^2/c^2}$, so that moving space exhibits forward compression, backward extension, and transverse extension. (3) A unified reduction of classical optical and relativistic experiments: the optical Doppler shift, Michelson–Morley experiment, Hoek experiment, Fizeau flowing-water experiment, Sagnac effect, and penetration distance of high-speed $\mu$ particles are all derived from the same length-vector factor, reducing effects conventionally ascribed to “time dilation” or “ether dragging” to directional changes in effective spatial paths.

To ensure rigorous closure of the theory as presented throughout the monograph, the scope of validity and theoretical boundaries of the kinematic model are specified here. First, the distinction between directed effective length and Euclidean positional coordinates: the LVE formula (1.13) describes the directed effective optical path defined by a photon's flight along the actual measurement direction $\hat{n}$ (the Randers-type directed line element containing a direction-odd term of first order, developed further in Chapter 5), rather than simply the norm of a static three-dimensional Euclidean coordinate vector. In an arbitrary closed round-trip optical path, the first-order direction-odd term $-(v/c)\cos\phi$ cancels exactly, leaving only the common even longitudinal/transverse factor $\gamma$.

Second, the boundary of ideal time–frequency standards and static gravitational-anisotropy corrections: the derivations in Sections II and III assume a uniform spatial background and ideally synchronized clocks. In particular, standard clocks are taken to be free of perturbations from external gravitational-potential gradients, mechanical stress, or nonuniform electromagnetic fields. In real terrestrial gravitational fields, around-the-world atomic-clock experiments (such as the 1972 Hafele–Keating experiment [19,20]) and satellite navigation time–frequency comparisons require, in addition to the kinematic LVE of Eq. (1.47), a correction for static spatial dilation arising from the gravitational-potential difference at different altitudes. This static spatial anisotropy and its gravitational-redshift law are developed in Chapter 2.

Third, the connection between the ideal nondispersive-medium approximation and microscopic field dynamics: Sections 3.3 and 3.4 express the optical path in a moving transparent medium as $L_{\mathrm{opt}} = nL$, which gives the reference kinematic response for a constant phase refractive index. If the Doppler shift within the moving medium is also allowed to change the refractive index with frequency ($dn/\mathrm{d}\lambda \neq 0$),

substitution of the wavelength correction in Eq. (1.22) into $n(\lambda')$ in Eq. (1.32) gives the full Lorentz–Lorenz dispersion correction term.

As the opening chapter of the monograph, this chapter establishes ASD's metrological–kinematic starting point. Chapter 2 extends the Length Vector Effect from pure kinematics to centre-of-mass energy, momentum, and the static spatial anisotropy of gravitational fields. Chapter 3 shows how the transverse directional factor $\gamma$ and the longitudinal factor govern the deformation of electromagnetic fields around moving charges and the origin of magnetic force. Chapters 4 and 5 then examine the longitudinal and transverse elastic degrees of freedom of the spatial lattice, closed topological cores, and motion-induced accompanying fields, completing the logical sequence from fundamental metrological definitions to a unified physical picture of matter, radiation, and gravitation.

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