A Shadow’s Edge Is Soft Not Because Light Bends Around It but Because the Sun Is Not a Point

— Against the Sun’s angular diameter of **1919.3** arcseconds (**0.533139** degrees), the penumbra widens in exact proportion to distance: **9.305029** mm at **1** m and **93.050290** mm at **10** m — the separator is whether the gap is larger or smaller than the Sun’s image — [Paper 671]

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— From thinking to syncing. —

Abstract

The edge of a shadow is soft. It is sometimes said that light bends around the obstacle, but in sunlight it is not diffraction that softens the edge.Taking the Sun to be not a point but a disc 0.533139 degrees across, the softness of the edge and the shape of dappled sunlight are counted.No new theorem or law is claimed. First, the penumbra widens in proportion to distance——against an angular diameter of 1919.3 arcseconds, the penumbra is 9.305029 mm at 1 m, 93.050290 mm at 10 m and 930.502898 mm at 100 m (Section 2). **Second, and this is the core. A small object loses its umbra almost at once——the umbra of an object 10 mm across ends at 1.074688 m, and one 1 mm across at 0.107469 m** (Section 2). **Third, beyond that, what falls is an image of the Sun and not the shape of the gap ——a gap of 5 mm becomes smaller than the Sun’s image beyond 0.537344 m, and what reaches the ground is a round image. This is why dappled sunlight is round** (Section 3). **Fourth, diffraction does not account for it——the diffraction scale at 1 m is 0.741620 mm, one 12.546899th of the penumbra there, and at 10 m one 39.676777th** (Section 2). **Fifth, the same geometry sets how narrow a solar eclipse is——the Moon’s umbra, 3.734325×10^{8} m long, is 0.971468 of its distance from the Earth, and only just reaches** (Section 3). **Sixth, the separator is whether the gap is larger or smaller than the Sun’s image——larger, and the gap’s shape falls; smaller, and the Sun’s shape does** (Section 4). **Keywords**: penumbra, umbra, angular diameter of the Sun, pinhole image, dappled sunlight, solar eclipse.

Scope of this paper (scope note): **No new theorem or law is claimed——the geometry of umbra and penumbra, the Sun's angular diameter, and the condition for a pinhole image are all standard (Minnaert 1954, Hecht 2017).Diffraction is not treated——a diffraction scale is computed only to compare, and the diffracted image itself is not calculated.No eclipse is predicted——the saros cycle, eclipse prediction and the track on the ground are not the subject.The solar disc is taken as uniform——limb darkening is not included, and the angular diameter is a representative value that varies through the year.Brightness is not computed——the distribution of brightness across the penumbra and the light a shadow receives from the blue sky are not treated. Only the width of the edge is examined.Relation to earlier papers**: **Paper 323 showed that the "three" in three primaries is a property of the receiver and not of light——here the softness of a shadow's edge is a property neither of the object nor of the receiver, but of the shape of the source.**What is added is **deriving the penumbra width by distance**, **deriving the distance at which the umbra ends by object size**, **deriving where gap and image trade places**, **putting a number on the ratio of diffraction scale to penumbra**, and **placing the separator on gap against image**.

1. Notation and the Question

Setting: **the Sun is not a point but subtends an angle θ. On a surface at distance L from an object, the edge of the shadow carries a penumbra of width θL, and the umbra of an object of diameter d ends at $L = d/\theta$.**

$$w = \theta L, \qquad L_{\text{umbra}} = \frac{d}{\theta}, \qquad \theta = 9.305029 \times 10^{-3}$$

Here θ is in radians, corresponding to the Sun's angular diameter of 1919.3 arcseconds.

Question: **is a shadow's edge softened by light bending around the obstacle, or by the extent of the source?**

2. The Penumbra and the End of the Umbra

Computation 2.1: **the penumbra width was derived by distance.**

distance	penumbra width
0.1 m	**0.930503** mm
1 m	**9.305029** mm
10 m	**93.050290** mm
100 m	**930.502898** mm

Ten times the distance gives exactly ten times the width; the proportionality holds.

Computation 2.2: **the distance at which the umbra ends was derived by object size: 0.107469 m for 1 mm, 1.074688 m for 10 mm and 10.746877 m for 100 mm.**

Computation 2.3: **the diffraction scale at 550 nm, the square root of wavelength times distance, is 0.741620 mm at 1 m and 2.345208 mm at 10 m, giving ratios to the penumbra of 12.546899 and 39.676777.**

> **Observation 2.4**
>
> **the softness does not come from diffraction.With distance, the diffraction scale grows only as a square root while the penumbra grows in proportion——so the gap widens with distance, reaching 39.676777 at 10 m. What makes the edge of a sunlit shadow is the extent of the source.**

3. When the Gap Is Small, the Sun's Shape Falls

Computation 3.1: **the size of a gap was compared with the size of the Sun's image on a surface at distance L.**

gap	distance	size of the Sun's image	what falls
5 mm	**3** m	**27.915087** mm	the image (round)
5 mm	**10** m	**93.050290** mm	the image (round)
20 mm	**3** m	**27.915087** mm	the image (round)

A gap of 5 mm equals the image at 0.537344 m, and beyond that the image wins.

> **Observation 3.2**
>
> **dappled sunlight is round, and not because the gaps between leaves are round.When the gap is smaller than the Sun's image, what falls on the ground is the shape of the Sun, not of the gap——whatever the gap's shape, what is cast is the shape of the source.**

Computation 3.3: **applying the same geometry to the Moon (radius 1.7374×10^{6} m), its umbra is 3.734325×10^{8} m long, which is 0.971468 of its distance from the Earth, 3.8440×10^{8} m.**

> **Observation 3.4**
>
> **totality is narrow because the umbra only just reaches.An umbra 0.971468 of the distance long is one whose tip runs out close to the surface——it is the same geometry by which a small object loses its umbra at 1.074688 m.**

4. The Separator

> **Observation 4.1**
>
> **the separator is whether the gap is larger or smaller than the Sun's image.Larger, and the gap's shape falls; smaller, and the Sun's shape does. The same gap trades places simply by moving the surface further away ——for a gap of 5 mm that boundary is 0.537344 m.**

> **Observation 4.2**
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> **beside Paper 323.Paper 323 showed that the "three" in three primaries is a property of the receiver——the softness here is a property neither of the object nor of the receiver, but of the source: light the same object with a nearly point source, a distant street lamp, and the edge sharpens.**

> **Observation 4.3**
>
> **what is not said.The diffracted image itself, the brightness across the penumbra, limb darkening and eclipse prediction are not treated——what is shown is that the width of a sunlit shadow's edge is set by the extent of the source and is an order above diffraction.**

5. Roll Call and Closing

1. **9.305029 mm at 1 m** (Computation 2.1): **the penumbra.**
2. **93.050290 mm at 10 m** (Computation 2.1): **in proportion to distance.**
3. **1.074688 m for 10 mm** (Computation 2.2): **the umbra ends.**
4. **0.107469 m for 1 mm** (Computation 2.2): **sooner still.**

5. **diffraction 0.741620 mm** (Computation 2.3): **at 1 m.**
6. **a ratio of 12.546899** (Computation 2.3): **39.676777 at 10 m.**
7. **the boundary at 0.537344 m** (Computation 3.1): **a gap of 5 mm.**
8. **dappled light is the Sun's shape** (Observation 3.2): **not the gap's.**
9. **the Moon's umbra is 0.971468 of the distance** (Computation 3.3): **only just reaching.**
10. **gap against image** (Observation 4.1): **the separator; Paper 323.**

Closing: **The edge of a sunlit shadow is not softened by light bending around the obstacle.Because the Sun is 0.533139 degrees across, the penumbra widens in proportion to distance, 9.305029 mm at 1 m and 93.050290 mm at 10 m, and an object 10 mm across loses its umbra at 1.074688 m.The diffraction scale at the same distance is 0.741620 mm, one 12.546899th of the penumbra——what softens the edge is the extent of the source.So when a gap is smaller than the image, what falls is the Sun's shape and not the gap's——for a gap of 5 mm the boundary is 0.537344 m, and beyond it dappled sunlight is round.The separator is whether the gap is larger or smaller than the Sun's image.Placed among the earlier papers——where Paper 323 called the "three" a property of the receiver, this softness is a property of the source.To be honest——neither the diffracted image nor the brightness across the penumbra was computed, and the angular diameter is a representative value.**

References

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