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Solar Eclipse Eye Safety

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Total solar eclipses are arguably the most spectacular astronomical events that anyone will experience in their lives. While annular and partial solar eclipses aren't nearly as impressive, they nevertheless attract a great deal of public interest. Astronomers (both amateur and professional) and other enthusiasts travel around the world to observe and photograph solar eclipses. This document is for them, i.e., for astronomers and other experts — including educators as well as medical and eye-care professionals — who may find themselves in the position of coaching laypersons through a solar eclipse and who want to understand in detail the principles of eye safety for observing the Sun.

Contents

A solar eclipse offers students a unique opportunity to see a natural phenomenon that illustrates the basic principles of mathematics and science taught through elementary and secondary school. Indeed, many scientists (including astronomers) have been inspired to study science as a result of seeing a total solar eclipse. Teachers can use eclipses to show how the laws of motion and the mathematics of orbits can predict the occurrence of eclipses. The use of pinhole cameras and telescopes or binoculars to observe an eclipse leads to an understanding of the optics of these devices. The rise and fall of environmental light levels during an eclipse illustrate the principles of radiometry and photometry, while biology classes can observe the associated behavior of plants, animals, and insects. It is also an opportunity for children of school age to contribute actively to scientific research; observations of contact timings at different locations along the eclipse path are useful in refining our knowledge of the orbital motions of the Moon and Earth, and sketches and photographs of the solar corona can be used to build a three-dimensional picture of the Sun's extended atmosphere during the eclipse.

Solar Retinopathy

Observing the Sun, however, can be dangerous if proper precautions are not taken. The solar radiation that reaches Earth's surface ranges from ultraviolet (UV) radiation at wavelengths longer than 290 nanometers (nm), to radio waves in the meter range. The tissues in the eye transmit a substantial part of the radiation between 380 and 780 nm to the light-sensitive retina at the back of the eye. While environmental exposure to UV radiation is known to contribute to the accelerated aging of the outer layers of the eye and the development of cataracts, the primary concern over improper viewing of the Sun during an eclipse is the development of “eclipse blindness” or retinal burns caused by high-intensity visible light.

Exposure of the retina to intense visible light causes damage to its light-sensitive rod and cone cells. The light triggers a series of complex chemical reactions within the cells that damages their ability to respond to a visual stimulus and, in extreme cases, can destroy them. The result is a loss of visual function, which may be either temporary or permanent depending on the severity of the damage.

When a person looks repeatedly, or with optical magnification, or for a long time at the Sun without proper eye protection, photochemical retinal damage may be accompanied by a thermal injury. The radiation that is not absorbed by the photoreceptors is absorbed by the retinal pigmented epithelium, where it is transformed into heat that literally cooks the exposed tissue. This thermal injury, or photocoagulation, destroys the rods and cones, creating a small blind area. The danger to vision is significant because photic retinal injuries occur without any feeling of pain (the retina has no pain receptors), and the visual effects may not become apparent until several hours after the damage is done (Pitts 1993). Note that this thermal injury does not result from exposing the retina to solar infrared (IR) radiation. Intense IR radiation can also cause thermal injury to the retina, but during solar observing the main thermal hazard is prolonged unprotected exposure to visible light, particularly at short (blue) wavelengths.

There are some concerns that ultraviolet-A (UVA) radiation (wavelengths from 315 to 380 nm) in sunlight may also adversely affect the retina (Del Priore 1999). While there is some experimental evidence for this, it applies only to the special case of aphakia, where the natural lens of the eye has been removed because of cataract or injury and no UV-blocking spectacle, contact lens, or intraocular lens has been fitted. In an intact normal human eye, UVA radiation does not reach the retina because it is absorbed by the crystalline lens. In aphakia, normal environmental exposure to solar UV radiation may indeed cause chronic retinal damage. The solar filter materials discussed in this article, however, attenuate solar UV radiation to a level well below the minimum permissible occupational exposure for UVA (American Conference of Governmental Industrial Hygienists, ACGIH 2015), so an aphakic observer is at no additional risk of retinal damage when looking at the Sun through a proper solar filter.

Retinal Safety Calculation

Detailed calculations and analysis of retinal hazards from direct viewing of the Sun demonstrate that a thermal injury of the retina is *normally* not possible unless the pupil is well dilated or unless the solar disk is viewed through binoculars or a telescope (White et al. 1971, Sliney and Wolbarsht 1980). The temperature rise in the irradiated retinal image is insufficient to produce a retinal burn for the unaided eye; even with a 3 mm diameter pupil (which would be quite large for bright daylight), the temperature rise will normally be less than 4°C (White et al. 1971, Sliney and Wolbarsht 1980, Mainster 1998).

The Sun instead poses a photochemical hazard (“blue-light hazard”), not from momentary viewing but from prolonged staring (as during a partial eclipse) for minutes. The terrestrial radiance of the Sun when overhead is approximately 1.3×10^7 W m^{-2} sr^{-1}; spectral weighting of the solar spectrum with the blue-light hazard function B(λ) provides effective blue-light radiance values ranging from 4×10^5 to 1.8×10^6 W m^{-2} sr^{-1}, depending on solar elevation angle greater than 10° above the horizon.

The maximum staring durations that relate to these blue-light radiances from the ACGIH (2015) limits vary from only 0.6 second for solar zenith to 2.5 seconds for the Sun at 10° above the horizon with very clear sky conditions (Hietanen 1991, Okuno 2008). Of course, actual injuries will occur only at greater durations, since the exposure limits incorporate a large safety factor and assume a relatively large pupil size of 3 mm, whereas the pupil typically will be only 1.5 to 2 mm under such viewing conditions.

The International Organization for Standardization (ISO) 12312-2 standard for filters for direct observation of the Sun (ISO 2015) specifies the spectral transmittance properties of protective filters that are considered safe for viewing the uneclipsed or partially (including annularly) eclipsed Sun.

To provide an example for calculating a required attenuation factor, consider a staring duration of 1,000 seconds (16⅔ minutes) with the Sun overhead under ideal conditions. One would need an attenuation factor of (1,000 s)/(0.6 s) = 1,667, which would correspond to a neutral filter having a luminous transmittance of 100%/1,667 = 0.06%. However, practice shows that one would find it very difficult to stare at the Sun for more than a few seconds, let alone for 1,000 seconds, with a filter transmitting 0.06% of the Sun's light. Most observers would find a luminance of ~10 kcd m^{-2} as an upper value that could be comfortably viewed. Since the luminance of the overhead Sun is 1.6 x 10^6 kcd m^{-2} (Karandikar 1955) a minimum attenuation factor of 160,000 would be required for comfortable viewing (i.e., visual transmittance < 0.0006% at solar noon). Hence the filter transmittances in the ISO 12312-2 standard are far lower than required to prevent retinal injury (solar retinopathy). Since the luminance of the solar disk decreases as the solar zenith angle increases, the comfortable luminous transmittance can be less than 0.00044%. Finally, at sunset, the solar disk is safe (though not necessarily comfortable) to view on the horizon without protection, as nearly all the blue light has been scattered out of the image (Sliney and Wolbarsht 1980, Okuno 2008).

One should not look directly at the uneclipsed Sun, or a partial or annular solar eclipse, or the partial phases of a total solar eclipse without the proper equipment and techniques. Even when 99% of the Sun's surface (the photosphere) is obscured during the partial phases of a solar eclipse, the remaining crescent Sun is still intense enough to cause a retinal photochemical injury, even though illumination levels are comparable to twilight and it seems safe to look without a protective filter (Chou 1981 and 1996, and Marsh 1982). Viewing the Sun through binoculars, a telescope, or other optical device without proper protective filters can result in immediate thermal retinal injury because of the high irradiance level in the magnified image. During a total solar eclipse the only time that the Sun can be viewed safely with the naked eye is during the brief total phase ("totality"), when the Moon completely covers the bright disk of the Sun, revealing the magnificent solar corona, which is about as bright as the full Moon and just as safe to look at. Outside of totality, and at all phases of an annular or partial solar eclipse, failure to use proper observing methods may result in permanent eye damage and severe visual loss. This can have important adverse effects on career choices and earning potential, because it has been shown that most individuals who sustain eclipse-related eye injuries are children and young adults (Penner and McNair 1966, Chou and Krailo 1981, and Michaelides et al. 2001).

Eclipse Eye Injury Statistics

Penner and McNair (1966) examined records of reported eye injuries among military personnel and their dependents following a partial solar eclipse seen over Hawaii in February 1962. They described clinical findings in 52 eyes of individuals who viewed the eclipse without protective filters. Half of the eyes recovered vision to 20/20 after 6 months.

Chou and Krailo (1981) summarized clinical findings of eclipse-related eye injuries in individuals seen by Canadian optometrists following the total eclipse of February 1979. Twenty cases were reported. They found that males under age 20 were more likely to sustain eclipse-related eye injuries and that the patients were aware of the dangers of unprotected viewing of the eclipse but chose not to comply with warning messages.

Michaelides et al. (2001) studied eclipse-related eye injuries reported by ophthalmologists in the United Kingdom following a solar eclipse in August 1999. The eclipse was total over Cornwall and partial over the rest of the British Isles. They reported 70 patients with recognizable retinal lesions following the eclipse. The majority of patients viewed the partially eclipsed Sun either without protective devices (56%) or through sunglasses (30%). The remaining 14% claimed to have used "eclipse glasses" or "welder's masks." No additional information about these devices was provided, so it is likely that some or all of them were homemade, not certified as safe, or otherwise deficient. In any case, all patients in this study recovered their vision after several weeks.

In advance of the 2017 August 21 total solar eclipse, a coordinated effort to inform educators, eyecare professionals, news media, and the general public about how to view the solar eclipse safely resulted in public awareness of the importance of using solar eclipse viewers that met the requirements of ISO 12312-2. Informal surveys of eyecare professionals across the U.S. and Canada showed that the number of patients reported with eclipse-related retinopathy was approximately 100. Advances in clinical imaging techniques allowed for the localization of the damage to discrete layers within the retina (Wu et al 2018). Patient demographics resembled the findings of Chou and Krailo (1981).

How to View a Solar Eclipse Safely

The same techniques for observing the Sun outside of eclipses are used to view and photograph annular solar eclipses and the partially eclipsed Sun (Sherrod 1981, Pasachoff 2000, Pasachoff and Covington 1993, and Reynolds and Sweetsir 1995).

Filters for Direct Viewing with the Unaided Eye

The Sun can be viewed directly only when filters specially designed to protect the eyes are used. Many of these filters have a thin layer of chromium alloy or aluminum deposited on their surfaces that attenuates both visible and near-infrared radiation. Always inspect a solar filter before use; if punctured, scratched, or otherwise damaged, discard it. Read and follow any instructions printed on or packaged with the filter. Always supervise children using solar filters.

- A popular inexpensive choice is aluminized polyester that has been specially made for solar observation. (This material is commonly known as "mylar," though the registered trademark "Mylar®" belongs to Dupont, which does not manufacture this material for use as a solar filter. Note that "space blankets" and aluminized polyester film used in gardening are *not* suitable for this purpose!) Aluminized polyester can be cut to fit any viewing device and does not break when dropped. Some aluminized polyester filters may have large (up to approximately 1 mm in size) defects in their aluminum coatings. A microscopic analysis of examples of such defects shows that despite their potentially alarming appearance, the defects arise from a hole in one of the two aluminized polyester films used in the filter. There is no large opening completely devoid of the protective aluminum coating. While this is a quality-control problem, the presence of a defect in the aluminum coating does not necessarily imply that the filter is hazardous. When in doubt, an aluminized polyester solar filter that has coating defects larger than 0.2 mm in size, or more than a single defect in any 5 mm circular zone of the filter, should not be used.

- An alternative to aluminized polyester is “black polymer” in which carbon particles are suspended in a resin matrix. This material is somewhat stiffer than polyester film and requires a special holding cell if it is to be used at the front of binoculars, camera lenses, or telescopes (see below). Intended mainly as a visual filter, the polymer gives a yellow-white image of the Sun (whereas aluminized polyester produces a blue-white image). This type of filter may show significant variations in density of the tint across its extent; some areas may appear much lighter than others. Lighter areas of the black polymer filter transmit more infrared radiation than may be desirable. Newer black-polymer filters often include a layer of aluminized polyester on one side to address these concerns.
- Welders’ filters with shade numbers 12 to 14, as specified in the occupational eye and face protector standard ANSI Z87.1, can be obtained from welding supply outlets. These are protective filters that are suitable for electric arc welding. Filters of lower shade numbers, for example, those intended for use with *gas* welding or cutting, are not safe. Even arc-welders’ filters should not be used in conjunction with telescopes (in front of the objective) for observation of the Sun, as their relatively poor optical quality will result in blurred images.

A recent study of solar eclipse glasses and viewers (Chou, Dain and Fienberg 2022) showed that the luminous transmittance limits of ISO 12312-2:2015 could be adjusted for visual comfort without affecting safety and that the uniformity limits were more conservative than necessary. Products must be tested for compliance by a properly accredited laboratory that issues a quantitative report.

Eclipse glasses or viewers should not be used unless they comply with the requirements of ISO 12312-2. They are not designed to look at the Sun through a camera, a telescope, binoculars, or any other optical device.

The selection of the welding filter shade number is a matter of personal preference in comfort and will depend on atmospheric conditions and personal glare sensitivity. Filters with shade number 12 should be adequate to protect the eyes, but the solar image may be uncomfortably bright. Some observers may find that the solar image viewed through a shade 14 filter is too dim. The table below compares the transmittance properties of welding and solar filters. In the visible spectral range, the values (from the ISO 12312-2 standard) are for luminous transmittance as specified in ANSI Z87.1.

Comparison of Transmittance Limits (%) of Solar & Welding Filters

Filter Type	**Ultraviolet spectral range**		**Visible spectral range**	**Infrared spectral range**
	280–315 nm	**315–380 nm**	**400–700 nm**	**780–1400 nm**
Solar[1]	0.0032	0.0032	0.0032	3
Welder’s SN[2] 12	0.0003	0.0012	0.0032	0.5
Welder’s SN[2] 13	0.0003	0.00044	0.0012	0.4
Welder’s SN[2] 14	0.00016	0.00016	0.00044	0.3

[1] Adapted from the ISO 12312-2:2015 standard. [2] SN = Shade No. and is for arc-welding, not gas-welding, filters.

It should be noted that welding filters are designed to protect against high irradiance levels of UV and IR radiation that are present in welding arcs and flames, along with the intense visible-light emission. These radiation hazards are not present to the same degree when looking at the Sun. As a result, the transmittance requirements specified for welding filters in the standards for occupational eye protection are more stringent than the ISO 12312-2 standard.

Eye protectors for direct observation of the Sun should be worn so that no direct radiation from the Sun can reach the eye other than that passing through the filter. During eclipses of the Sun, eye protectors must be worn to look at the Sun whenever a part of the solar disk is *not* covered by the Moon, i.e., during partial or annular eclipse. The only time it is safe to view a solar eclipse without eye protection is when the Moon completely covers the photosphere in a total eclipse, i.e., between the beginning and ending diamond ring effects.

Indirect Viewing by Solar Projection

An alternative to direct viewing of the Sun with filters is indirect viewing, often called projection. Indirect methods usually involve a pinhole or small opening to form an image of the Sun on a screen or nearby surface, such as the ground or a wall.

- A pinhole in a card can be used to project an image on a screen or surface placed about a meter/yard beyond the opening. *Do not look at the Sun through the pinhole; the Sun should be at your back when doing pinhole projection.* Multiple openings in perfboard, a loosely woven straw hat, a pasta colander, or even interlaced fingers can be used to cast a pattern of solar images on the ground or on a screen. A similar effect is seen on the ground beneath a leafy tree: the many “pinholes” formed by overlapping leaves create hundreds of crescent-shaped or ring-shaped images during the partial or annular phases, respectively, of a solar eclipse.
- Binoculars or a small telescope mounted on a tripod can also be used to project a magnified image of the Sun onto a white card. But great care must be taken to ensure that no one looks through the unfiltered device, and any finder scope or other auxiliary optics should be removed or covered.
- A small mirror can be used to project an image of the Sun onto an adjacent shaded wall or more effectively projected through an open window into a darkened room.

Each of these methods can be used to provide a safe view of the partial phases of an eclipse and are useful when there is a group of observers. The main advantage of the projection methods is that nobody is looking directly at the Sun, but there are also disadvantages. With the pinhole method the screen must be placed at least a meter/yard behind the opening to get a sizeable solar image. The projected image tends to be dull and of poor resolution, and safety precautions are essential with optical projection to ensure that nobody looks into the eyepiece or stands in the path of the projected beam. A novel solar-projection device that solves most of these problems is the Sun Funnel, which fits in a telescope focuser in lieu of a regular eyepiece and is easy to build using inexpensive, readily available supplies and household tools (Fienberg et al. 2012). The Sun Funnel completely encloses the sunbeam coming from the telescope and forms a high-quality, magnified solar image on a rear-projection screen.

Filters for Camera Lenses, Binoculars & Telescopes

The advent of high-resolution digital imaging in astronomy, especially for photographing the Sun, has increased the demand for solar filters of high optical quality. *No solar filter should be used with an optical device (e.g., binoculars, telescope, camera) unless it has been specifically designed for that purpose and is mounted at the front (objective) end.*

- A metal-coated 1 mil resin film can be used for both visual and photographic solar observations. Being much thinner than polyester film, it has excellent optical quality and much less scattered light than metal-coated polyester filters.

- Filters using metal-coated, optically flat glass substrates are available from several manufacturers but are more expensive than polyester and black polymer filters.

Note that it is safe to look at the totally eclipsed Sun with unfiltered optics as long as care is taken to avoid watching as totality ends and bright sunlight reappears from behind the Moon.

Unsafe Filter Materials

In the past, experienced solar observers used filters made with one or two layers of black-and-white film that was fully exposed to light and developed to maximum density. These films had a silver-based emulsion. Since modern black-and-white films are less likely to contain silver, this type of solar filter is no longer recommended.

The following materials are *unsafe* and should *never* be used for solar viewing. Even if the Sun appears dim or no discomfort is felt when looking at the Sun through these materials, there is no guarantee that the eyes are safe.

- "Black" developed color film
- Exposed film negatives
- Sunglasses (single or multiple pairs)
- Photographic neutral-density filters
- Food wrappers (e.g., chips, Pop Tarts)
- Polarizing filters
- Smoked glass
- CDs or DVDs
- "Space blankets"
- Gardening films or similar products

Solar filters designed to thread into, or fit over, eyepieces that are often provided with inexpensive telescopes are also unsafe. These glass filters often crack unexpectedly from overheating when the telescope is pointed at the Sun, and retinal damage can occur faster than the observer can move the eye from the eyepiece. Eyepiece solar filters should be discarded.

Local planetariums, science centers, and amateur astronomy clubs can provide additional information on how to observe the Sun safely.

A Warning About Warning Messages

In the days and weeks before a solar eclipse, there are often news stories and announcements in the media warning about the dangers of looking at the eclipse. Unfortunately, despite the good intentions behind these messages, they frequently contain misinformation and may be designed to scare people from viewing the eclipse at all. This tactic may backfire, however, particularly when the messages are intended for students. A student who heeds warnings from teachers and other authorities not to view the eclipse because of the danger to vision, and who later learns that other students did see it safely, may feel cheated out of the experience. Having now learned that the authority figure was wrong on one occasion, how is this student going to react when other health-related advice, such as about drugs, acquired immunodeficiency syndrome (AIDS), or smoking is given (Pasachoff 2001)? Misinformation may be just as bad, if not worse, than no information.

Closing Thoughts

Remember that the total phase of a solar eclipse can, and *should,* be observed without any filters, and certainly never by projection! *It is completely safe to do so.* The naked-eye view of the totally eclipsed

Sun — featuring the solar corona ringing the black silhouette of the Moon in a twilight-dark sky with sunset colors all around the horizon — is truly awe-inspiring. The experience should be enjoyed by all!

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About the Author

Dr. B. Ralph Chou received his BSc (Hons) in astronomy and astrophysics from the University of Toronto and then attended the University of Waterloo School of Optometry. From 1982 to 2012 he taught optics, environmental vision, and optometric jurisprudence at Waterloo, retiring as Professor Emeritus in the School of Optometry & Vision Science. His research interests include environmental and occupational hazards to the eye, impact resistance of ophthalmic lens and frame materials, ophthalmic and visual standards, optics of progressive addition lenses, and assessment of professional clinical competency.

A solar eclipse chaser since his teens, Dr. Chou has written scholarly and popular articles on solar eclipse eye safety. He was lead writer for the ISO 12312-2 standard on filters for direct observation of the Sun and is widely recognized as a leading expert on protective solar filters.

At various times in his distinguished career Dr. Chou has served as Chair of the Canadian Standards Association Technical Committee on Industrial Eye and Face Protection, member of the ISO technical subcommittees on eye protection and ophthalmic optics, Editor in Chief of the *Canadian Journal of Optometry,* President of the Science Teachers' Association of Ontario, President of the Toronto Centre of the Royal Astronomical Society of Canada, Registrar of the College of Optometrists of Ontario, and Co-Director of the David Dunlap Observatory. He is a Fellow of the American Academy of Optometry.

Notes:

- Some text in this document is adapted from Annexes A and B of the ISO 12312-2:2015 standard, which were written by the author.
- This paper does not constitute medical advice. Readers with questions should contact a qualified eyecare professional.