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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Analyzing Stress in Glass[1]

This standard is issued under the fixed designation F 218; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the analysis of stress in glass by means of a polarimeter based on the principles developed by de Sénarmont and Friedel (**1,2**).[2] Stress is evaluated as a function of optical retardation. Retardation is expressed as the angle of rotation of an analyzing polarizer that causes extinction in the glass.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Polarimeter

2.1 The polarimeter shall consist of an arrangement similar to that shown in Fig. 1. A description of each component follows:

2.1.1 *Source of Light*—Either a white light or a monochromatic source such as sodium light (λ 589 nm) or a mercury-vapor arc lamp of the high-pressure type, preferably the latter.

NOTE 1—The white light should provide a source of illumination with solar temperature of at least that of Illuminant A.

2.1.2 *Filter*— In order to render the light monochromatic, a narrow band-pass filter should be used.

2.1.3 *Diffuser*—A piece of opal glass or a ground glass of photographic quality.

2.1.4 *Polarizer*—A polarizing element housed in a rotatable mount capable of being locked in a fixed position.

2.1.5 *Immersion Cell*—Rectangular glass jar with strain-free sides filled with a liquid having the same index of refraction as the glass specimen to be measured. It may be surmounted with a suitable device for holding and rotating the specimen, such that it does not stress the specimen.

NOTE 2—Suitable index liquids may be purchased or mixed as required. Dibutyl phthalate (refractive index 1.489), and tricresyl phosphate (index 1.555) may be mixed to produce any desired refractive index between the two limits, the refractive index being a linear function of the proportion of one liquid to the other. Other liquids that may be used are:

Liquid	Refractive Index
Cinnamic aldehyde	1.62
Oil of cassia	1.61
Monochlorobenzene	1.525
Carbon tetrachloride	1.463
Dipentene (Eastman)	1.473

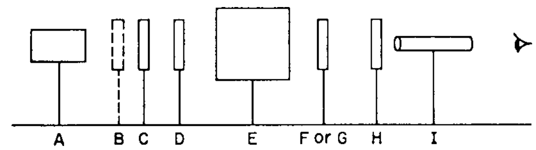
NOTE 3—Cases may arise where the refraction liquid may contaminate the specimen. If it is viewed through sides that are essentially parallel elimination of the liquid will cause only a minor error. However, when viewing through sides that are not parallel, the use of a refraction liquid is essential.

2.1.6 *Full-Wave (Sensitive Tint) Plate*, having a retardation of 565 nm which produces, with white light, a violet-red color. It should be housed in a rotatable mount capable of being locked in a fixed position.

2.1.7 *Quarter-Wave Plate*, having a retardation equivalent to one quarter of the wavelength of light being used. It should be housed in a rotable mount capable of being locked in a fixed position.

2.1.8 *Analyzer*—Identical to the polarizer. It should be housed in a rotatable mount capable of being locked in a fixed position. This mount must then be housed within a graduated mount capable of being rotated 360°.

2.1.9 *Telescope*, short-focus, having a suitable magnifying power over the usable focusing range.



A—Light source (white, sodium vapor, or mercury vapor arc)
B—Filter (used only with mercury arc light)
C—Diffuser
D—Polarizer
E—Immersion cell
F—Full-wave plate (used only with white light)
G—Quarter-wave plate
H—Analyzer
I—Telescope

FIG. 1 Polarimeter

3. Setup of Polarimeter

3.1 As usually employed, the polarimeter measures retardations in a vertical or a horizontal direction. This is accomplished by setting the vibration direction of the polarizer at an angle of 45° to the vertical and horizontal in either a northwest-southeast or a northeast-southwest direction (Fig. 2). The

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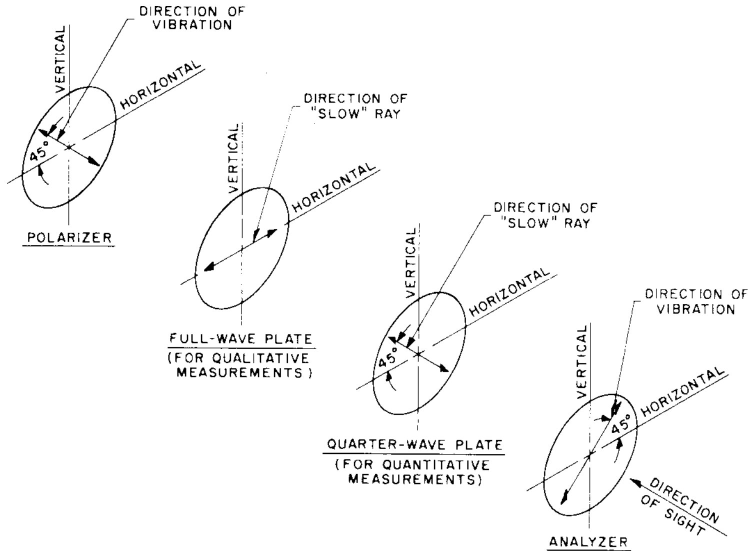
[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references at the end of this test method.



NOTE 1—The directions of vibration of the polarizer and analyzer may be oriented 90° from the indicated positions.

FIG. 2 Orientation of Polarimeter in Standard Position

vibration direction of the analyzer must be "crossed" with respect to that of the polarizer; that is, the two directions must be at right angles to each other. In this relationship a minimum amount of light will pass through the combination. To check the 45° angle at which the directions of the polarizer and analyzer must be set, use may be made of a rectangular-shaped Glan-Thompson or Nicol prism. The prism is set so that its vibration direction is 45° to the vertical and horizontal. The polarizer is then rotated until extinction occurs between it and the prism. The position of the analyzer is then determined in the same way, but by first rotating the Glan-Thompson or Nicol prism through 90°; or, the analyzer may be rotated to extinction with respect to the polarizer after the latter has been set in position with the prism.

3.2 When a quarter-wave plate is used, its "slow" ray direction must be set in a northwest-southeast direction (Fig. 2). Adjusted in this position, maximum extinction occurs when direction of axes of all three elements (polarizer, analyzer and quarter-wave plate) are in agreement with Fig. 2.

3.3 When the full-wave plate is used with the quarter-wave plate, its "slow" ray direction must be placed in a horizontal position (Fig. 2). Adjusted in this position, a violet-red background color is seen when the three elements (polarizer, full-wave plate, and analyzer) are placed in series.

3.4 Paragraphs 3.2 and 3.3 describe orientations of the quarter- and full-wave plates in the standard positions that have been generally adopted. However, the direction of the" slow" rays may be rotated 90° without changing the functions of the apparatus. This does, however, cause the analyzer rotations (in the case of the quarter-wave plate) and the colors (in the case of the full-wave plate) to have opposite meanings. Table 1 and Table 2 define these meanings in whatever is being measured or observed with the "slow" ray directions in either the standard or the alternate positions.

3.5 To assure proper orientation of the directions of the "slow" ray of the quarter-wave and full-wave plates with respect to the vibration directions of the polarizer and analyzer, use may be made of a U-shaped piece of annealed cane glass as illustrated in Fig. 3. Squeezing the legs together slightly will develop a tensile stress on the outside and a compressive stress on the inside. Then, if the" slow" ray directions of the quarter-wave and full-wave plates are oriented in the standard positions, the stress conditions of Columns 1 through 4 and 9 through 12 of Table 1 and Table 2 will be noted in the vertical

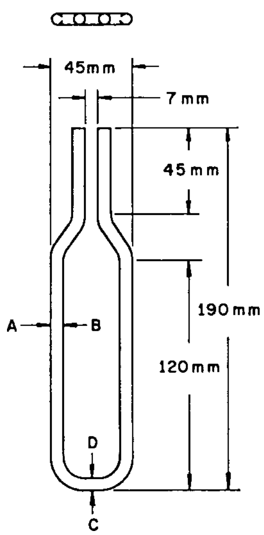
TABLE 1 Orientation of" Slow" Ray Direction of Quarter-Wave Plate with Corresponding Stresses

When orientation of "slow" ray with respect to the horizontal is:	(standard)				(alternate)			
and when stress component lies in the	vertical		horizontal		vertical		horizontal	
then rotation[A] of analyzer:	clockwise	counter-clockwise	clockwise	counter-clockwise	clockwise	counter-clockwise	clockwise	counter-clockwise
indicates:	tension	compres-sion	compres-sion	tension	compres-sion	tension	tension	compres-sion
column: (see 3.5)	1	2	3	4	5	6	7	8

[A] If the analyzer must be rotated in a clockwise direction to obtain extinction at a given point, the retardation is arbitrarily called positive (+). If the analyzer must be rotated in a counterclockwise direction, the retardation is arbitrarily negative (−).

TABLE 2 Orientation of "Slow" Ray Direction of Full-Wave Plate with Corresponding Stresses

When orientation of" slow" ray with respect to the horizontal is:	(standard)				(alternate)			
and when stress component lies in the:	vertical		horizontal		vertical		horizontal	
then the approximate color:	yellow	green	yellow	green	yellow	green	yellow	green
indicates:	tension	compres-sion	compres-sion	tension	compres-sion	tension	tension	compres-sion
column: (see 3.5)	9	10	11	12	13	14	15	16



NOTE 1—When the legs are squeezed together, Sides A and C become tensile and Sides B and D become compressive.

NOTE 2—Material—Cane glass of approximately 7 mm diameter, annealed after forming.

NOTE 3—When viewed in the polarimeter, immerse in a liquid having the same refractive index as the glass.

FIG. 3 Reference Specimen

and horizontal sides of the U-tube. If the conditions of the other columns are preferred, it will be necessary to rotate the "slow" ray directions 90° to the alternate positions.

3.6 If a major stress component lies in any direction other than vertical or horizontal, its measurement requires that the entire optical system be rotated so that the vibration directions of the polarizer and analyzer are set at 45° to the stress direction, or that the part containing the stress direction be rotated to suit.

4. Procedure

4.1 To measure the retardation at any given point, rotate the analyzer with respect to its initial position until maximum extinction (darkness) occurs at the point. Note this by the closing of a looped-shaped fringe until it merges into a small dark area. The angle through which the analyzer must be rotated to the left or the right is a measure of the retardation at the point. When it is required that the retardation be measured in a given area or section where several extinction points may exist rotate the analyzer to the right or left until the maximum of the extinction points is visible. The point at which retardation is to be measured or the general area at which the maximum retardation is to be measured must be specified.

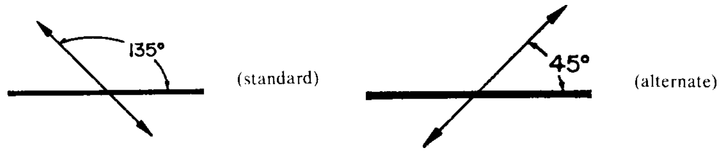
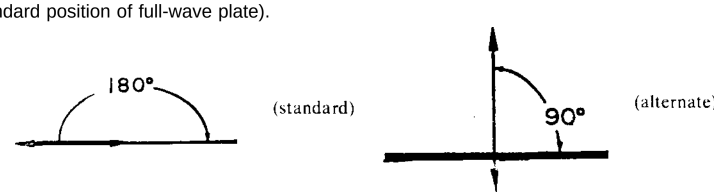
4.2 When a maximum value is specified and the specimens are of a uniform thickness it is necessary only to set the analyzer at the angle specified and then observe whether any unclosed loop-shaped fringes are present in the stress pattern. If not, it may be concluded that the maximum retardation that is present is less than the specified maximum. If any are present, then the retardation is greater than the specified maximum. To determine the exact magnitude of the retardation, use the method outlined in 4.1.

4.3 When the full wave plate (also called the "tint plate") is introduced, the polarimeter can be used to reveal a color pattern. White light must be used for this observation, and the analyzer must be set in standard position (perpendicular to the polarizer). Table 3 shows the color distribution that may be expected together with the associated magnitude of the retardation.

4.4 When the specimen is very small, accurate evaluation of retardation with the polarimetric arrangement described becomes difficult when the magnification offered by the telescope is too low. For such specimens use a polarizing microscope containing all the basic elements of Fig. 1. Because the optic axis of the microscope is usually vertical, place the object to be observed in a strain-free glass containing the refraction liquid. A major difference may exist, however: In the polarizing microscope, the vibration directions of the polarizer and analyzer are normally crossed in north-south and east-west positions. Accordingly, the "slow" ray directions of the quarter-wave and full-wave plates are oriented 45° counterclockwise to the standard positions of Table 1 and Table 2. This simply means that the "vertical" position of the stress component is now in a northwest-southeast orientation, but it does not change the meanings of the stress directions. In essence, the polarizing microscope usually has its directions of vibration rotated 45° counterclockwise to that shown in Fig. 2.

4.4.1 When it becomes necessary to measure retardations in excess of 180° rotation of the analyzer, use a Berek rotary compensator or quartz wedge compensator (Babinet or Babinet-Soleil), capable of measuring retardations up to 4 or more orders (4 or more times the wavelength of the light source), in place of the quarter-wave plate.

TABLE 3 Polariscopic Colors with White Light

Color (approx)		Equivalent optical retardation (approx) in degrees rotation of analyzer
Orange	312	Colors on this side of line indicate compression in the vertical and tension in the horizontal (standard position of full-wave plate).
Yellow	287	
Green	245	
Blue green	212	
Violet	178	
Red	153	
Orange	128	
Pale yellow	110	
Greenish yellow	97	
Yellowish green[A]	85	
Pale green	73	
Green[A]	60	
Deep green	50	
Blue green[A]	40	
Blue	25	
Dark blue[A]	12	
Violet blue	7	
Violet red	0	
Red[A]	7	Colors on this side of line indicate tension in the vertical and compression in the horizontal standard position of full-wave plate).
Red orange	12	
Orange[A]	25	
Orange yellow	40	
Gold yellow[A]	50	
Yellow	60	
Pale yellow[A]	73	
Yellow white	85	
White[A]	97	
Gray white	110	
Iron gray	172	
Black	180	

[A] More distinctive color of pair.

5. Keywords

5.1 glass; optical retardation; polarimeter; stress

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