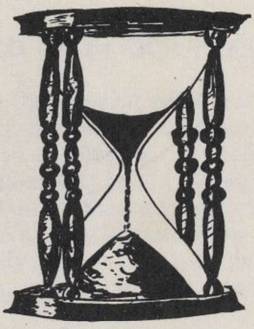
THE RHEOLOGY LEAFLET



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Publication

of the

SOCIETY OF RHEOLOGY

No. I March 1937

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With this number, the Rheology Leaflet makes its bow to our members. Further numbers will be issued from time to time as occasion warrants and the finances of The Society of Rheology permit. The Editor of the Society would be glad of suggestions as to the content of future numbers. He would appreciate, too, news items telling of the activities of rheologists for publication. Address: Wheeler P. Davey, School of Chemistry and Physics, The Pennsylvania State College, State College, Pennsylvania.

A WORD FROM OUR PRESIDENT

Since 1932, when the Journal of Rheology ceased publication, the Society of Rheology has had no medium for publishing general news items of interest to rheologists. Announcements of meetings, of course, have been published; but in addition to such official business there are always many other matters which ought to be circulated among our members. These matters are not important in themselves, taken individually; but taken collectively they constitute the life blood of the Society, and are necessary to its activity and growth.

Apparently, then, we need in the Society some newsy, gossipy little journal to supplement our publication of scientific papers in the Journal of Applied Physics. In order to meet this need the Executive Committee has authorized the launching of the Rheology Leaflet. It is hoped that you will all send in suggestions, contributions, and news items, and thus help the Editor to make the Leaflet just what you want it to be.

MELVIN MOONEY.

OUR LAST MEETING

Those of you who attended our meeting in the Hotel Pennsylvania in New York, October 29-31, 1936, will remember it as one of the most successful meetings we ever had. The big crowd of physicists from the colleges and from the industries; the joint meetings on physics and physicists in industry sponsored by The American Institute of Physics; the simultaneous meetings of the founder societies of the Institute; the very interesting program of our own Society of Rheology; the joint dinner of all the five founder societies of the American Institute of Physics; all these made an impression which will not soon be forgotten.

THE SOCIETY OF RHEOLOGY

The Society of Rheology is devoted to the study of the flow and deformation of matter. The breadth of the subject is such as to bring into our membership men of many fields of specialization. The study of the viscosities of fluids under various conditions of temperature, pressure, and rate of flow, attracts men from the asphalt, rubber, glass, paint, and petroleum and lubrication industries; the study of the elastic and plastic properties of solids brings in men from the metal and rubber groups as well as the theoretically inclined mechanical engineers; the study of the moldability of plastics and "molded compounds" attracts still another group. And then there are the college professors, the professor of physics, the professor of physical chemistry, the professor of metallurgy and the professor of ceramics. What group has your Editor missed in the above? When you have thought it all over, make a list of the omissions and send it to the Editor—he will quote you in the next issue.

It turns out that all these men are not in separate groups after all. The fundamental principles behind their work are strikingly similar, even though the application of the principles may fall in widely different fields. Each group of our members can help the other groups, and each member will find that the solution of the other fellow's problems helps him in his own work.

Rheology papers which are of a research nature or which show striking industrial applications of physical principles are published in the Journal of Applied Physics. If you haven't seen a copy of this most interesting monthly journal you have missed a real treat. The regular subscription rate is $7.00. Since the Society of Rheology is one of the five founder societies of the American Institute of Physics, our full members receive the Journal of Applied Physics as part of their return for their annual dues of $6.00. If you are now a subscriber but don't belong to The Society of Rheology, better join, and get your Journal of Applied Physics through the Society of Rheology.

TO OUR COLLEGE STUDENT MEMBERS

Associate members of the Society of Rheology pay annual dues of $2.50. This includes a subscription to the Review of Scientific Instruments. Associate membership is especially advantageous to college students specializing in physics and physical chemistry and their applications, because its low dues are purposely adjusted to the college student's purse. Every student should think of his life work as a profession, and not merely as a job. He owes it to his prospective profession to show his professional spirit by joining a professional society interested in his major subject. Of the five founder societies of the American Institute of Physics, the Society of Rheology is the only one which has made a special rate, (associate membership), available to students. It is hoped that, in so doing, the Society of Rheology may help you to cultivate a real professional spirit. Employers say that a physicist or chemist who hasn't enough professional spirit to join his professional society isn't worth hiring. How about it? Are they right? Incidentally, we hope that as our student members graduate from college and their financial conditions improve, they will become full members of the Society of Rheology and, besides, will join some of the other founder societies of the American Institute of Physics.

A membership application blank is included on the last page. How about getting your fellow student to fill it out and send it in now? If he is a member of the physics honor society, Sigma Pi Sigma, and sends his application through the Sigma Pi Sigma national executive secretary, the national office will pay $2.00 towards the first year's dues. Application blanks and full instructions are in the hands of every local chapter secretary of Sigma Pi Sigma. Ask him about them.

SUSTAINING MEMBERS

We wish to express our deep appreciation of the support given by our sustaining members. They are:

Bell Telephone Laboratories, New York City,
The Chemical Foundation, New York City,
Koppers Products Co., Pittsburgh, Pa.,
U. S. Rubber Products, Inc., Passaic, N. J.

A TRIBUTE TO OUR RETIRING EDITOR AND SECRETARY

Professor Eugene C. Bingham, Head of the Chemistry Department of Lafayette College, who has been editor of the Society of Rheology clear from the beginning, has resigned because of orders from his physician. We all realize how much time and effort Dr. Bingham has contributed toward the success of the Society of Rheology. Here is wishing him speedy restoration to health and many years to work for the advancement of Rheology.

Dr. A. Stuart Hunter, of the Research Laboratory of the Rayon Division of E. I. duPont deNemours and Company, who has been secretary of the Society of Rheology since the Society was founded, has been compelled to resign after a severe illness. We all appreciate deeply Dr. Hunter's constant and tireless service to the Society of Rheology and hope that he will soon recover all his former strength and vigor. Dr. Hunter continues his services to the Society of Rheology by being a member of the Board of Editors of The Journal of Applied Physics.

A QUESTION

Would you be interested from time to time in bibliographies of the current literature in Rheology? Would you like to see such a bibliography in each issue of the Rheology Leaflet? If so write the Editor at once:

Wheeler P. Davey, Editor,
Society of Rheology,
School of Chemistry and Physics.
The Pennsylvania State College,
State College, Pennsylvania.

REPORT OF THE COMMITTEE ON DEFINITIONS AND NOMENCLATURE

Comments and criticisms concerning the following report will be welcomed, whether coming from members or non-members of the Society. They should be addressed to Prof. E. C. Bingham, Lafayette College, Easton, Pa.

A REPORT ON RHEOLOGICAL DEFINITIONS AND NOMENCLATURE SUGGESTED FOR DISCUSSION

Foreword

In the following report by the Committee on Definitions and Nomenclature, an attempt is made to develop a complete, logical and self-consistent system of classification of materials according to their rheological properties. It is intended that the system shall provide a classification for all conceivable types of behavior of materials in deformation. The system has been developed on the basis of current usage to the extent permitted by logic and self-consistency.

The classification and the accompanying definitions have been developed in terms of idealized materials to which actual materials can be compared. In other words, ideal types of behavior and deformation are postulated which are susceptible of exact definition and classification. Actual materials can then be described in terms of the ideal types to which their behavior approximates. It should be borne in mind that an actual material with rheological properties coinciding exactly with those of a single idealized material is the exception rather than the rule. In applying to actual materials the quantitative definitions for idealized materials, great caution must be used.

It is recognized that the classification of a particular material may sometimes depend upon the method of measurement. This is particularly true as applied to the precision attained. The recognition of a measurable "yield stress," for example, may depend upon the precision of the measurement and upon the duration of the test. These uncertainties in the classification of materials result from the fact that it is sometimes either impossible or unimportant to determine for actual materials some of the characteristics which can be theoretically distinguished.

In this system of classification and definitions, only shearing strains and stresses are of interest, and the relations involved are expressed with reference to simple shear. Many of the concepts defined here in terms of simple shear are closely related to those usually defined by engineers in terms of more complex types of deformation, such as those arising in tension and compression tests. These deformations, while involving simultaneous shears in three dimensions and hence analytically complex, are often easier to produce experimentally than a simple shear. They, therefore, serve as a basis for many useful and practical concepts and definitions in the field of engineering. Where an analysis of the fundamental behavior of the material in deformation is required, these engineering tests may be reduced to a combination of shears, and described in terms of the concepts used in this report.

A general relation between strain and stress applies to any point within a material, and, except in extraordinary circumstances, these values will vary at different points. The quantities involved in these relations applying to individual points within the material cannot be observed directly. Observable quantities such as efflux-rate, pressure, etc., can be obtained by integrating the basic point relations and can then be compared with the values obtained experimentally. It is, however, always possible, at least formally, to devise experiments and methods of analysis by which the fundamental relationship can be completely determined from experimental data.

Although all materials exhibit the inertia effects associated with acceleration of the mass elements within the material, these effects are ignored as being irrelevant in the classification and definitions given below. It should be noted that turbulence and related hydrodynamical properties belong in this category.

Classification

The classification of idealized types of materials is in terms of their behavior under load, or the relation between strain and stress. The stress at any point within a material is a function of the strain and its time derivative, or rate of strain. In all materials the second time derivative of strain is effective in accordance with the inertia effect. As noted above, this effect is ignored in these definitions as common to all materials.

In addition to the instantaneous values of the strain and rate of strain, the stress may depend on the prior strain or deformation history of the material. Such dependence upon the prior strain is regarded for convenience as a secondary characteristic, materials being classified primarily by the relation between stress and instantaneous strain or rate of strain without regard to whether or not this relationship is affected by the prior strain.

When materials are classified according to their behavior under a shearing stress system, the usual classification is into fluids and solids, fluids including the two sub-classifications, gases and liquids.

Fluid:

A fluid is a substance which undergoes continuous deformation when subjected to any system of finite shearing stress.

Solid:

A solid is a substance which undergoes permanent deformation or rupture only when subjected to a system of shearing stresses which exceeds a certain minimum value.

Classes of Fluids:

As stated above, fluids include gases and liquids. The distinction between a gas and a liquid depends upon the behavior under hydrostatic pressure changes. The precise nature of this distinction and its disappearance above the critical temperature are complicated matters which are adequately discussed in the standard text books. It is unnecessary to repeat such a discussion here, especially in view of the fact that the basis for rheological classifications and definitions is the behavior under shearing stresses, as contrasted with uniform pressures.

Gases:

All gases are similar in their rheological properties, obeying the equation:

$$\frac{dv}{dr} = \frac{1}{\eta} F$$ (See Summary)

Classes of Liquids:

(a) A **Simple** (Newtonian) **Liquid** is one in which the rate of shear is proportional to the shearing stress, i.e.:

$$\frac{dv}{dr} = \frac{1}{\eta} F$$ (See Summary)

(b) A **Complex** (Non-Newtonian) **Liquid** is one in which the rate of shear is not proportional to the shearing stress. In general a complex liquid obeys the relation:

$$\frac{dv}{dr} > 0, \quad F > 0$$ (See Summary)

Classes of Solids:

(a) A **Plastic Solid** is one which does not deform under a shearing stress until the stress attains a critical value (yield stress), when the solid deforms so readily or so quickly that, except for inertia effects, the stress never exceeds the yield stress.

$$\varepsilon = 0,\ 0 < F < F_0$$

$$\varepsilon > 0,\ \frac{dv}{dr} > 0,\ F = F_0 \qquad \text{(See Summary)}$$

Reduction of the shearing stress below the yield stress results in the rate of deformation vanishing. No recovery takes place.

(b) An **Elastic Solid** is one for which the shearing strain is a single-valued function of the shearing stress for all values of the shearing stress below the rupture stress (shear strength). Symbolically,

$$\varepsilon = f(F) > 0,\ \frac{d\varepsilon}{dF} > 0,\ 0 < F < F_\infty \qquad \text{(See Summary)}$$

(c) A special case of an elastic solid is the **Hookian Solid** for which the shearing strain is proportional to the shearing stress for all values of the shearing stress below the rupture stress. Symbolically, this may be expressed by the relation:

$$\varepsilon = \frac{1}{G} F,\ 0 < F < F_\infty \qquad \text{(See Summary)}$$

Reduction of the shearing stress to zero results in the strain vanishing. There is no permanent set in an elastic solid.

(d) An **Elastico-Plastic Solid** is one which obeys the law of an elastic solid for values of the shearing stress below the critical stress corresponding to the elastic limit in shear, and deforms plastically when the shearing stress exceeds that value. Symbolically, this may be expressed by the relations:

$$\varepsilon = f(F) > 0,\ \frac{d\varepsilon}{dF} > 0,\ 0 < F < F_c$$

(See Summary)

$$\varepsilon > 0,\ \frac{dv}{dr} > 0,\ F = F_c$$

Reduction of the shearing stress to zero results in an immediate recovery. The permanent deformation is equal to the plastic deformation undergone.

(e) An **Elastico--Viscous Solid** is one which obeys the laws of an elastic solid for values of the shearing stress below the critical stress corresponding to the elastic limit in shear and deforms continuously at a rate of shear which is a function of the shearing stress, when the shearing stress exceeds that value. Symbolically, this may be expressed by the relations:

$$\varepsilon = f(F) > 0, \frac{d\varepsilon}{dF} > 0, 0 < F < F_c$$

(See Summary)

$$\varepsilon > 0, \frac{dv}{dr} > 0, F > F_c$$

Reduction of the shearing stress to zero results in a recovery which proceeds at a continuously decreasing rate. After an infinite recovery time, no permanent deformation remains.

(f) A **Plastico-Viscous Solid** is one for which no deformation occurs for values of the shearing stress below the yield stress and, for values of the shearing stress above that value, deforms continuously at a rate of shear which is a function of the shearing stress. Symbolically, this may be expressed by the relations:

$$\varepsilon = 0, 0 < F < F_0$$

(See Summary)

$$\varepsilon > 0, \frac{dv}{dr} > 0, F > F_0$$

Reduction of the shearing stress to a value below the yield stress results in the rate of shear vanishing. No recovery takes place.

Prior Strain:

The classification given above is without regard to prior strain. When the terms defined above are used without qualification, it is implied that the stress-strain relation is independent of the strain previously experienced. Materials for which the stress-strain relation is dependent on prior strain should be described as **Thixotropic** or **Strain Hardening** in the senses in which these terms are defined below.

General Remarks:

Again it should be noted that actual materials seldom yield rheological curves which exactly coincide with the idealized diagrams which have been employed in this report. However, no general relation exists which will describe the rheological behavior of all materials and it thus seems necessary to resort to these idealized classifications. It is hoped that they will serve at least for the approximate cataloging of the great number of actual materials.

Definitions

Descriptive Definitions:

Consistency is the resistance to flow of a material. (See Quantitative Definitions).

Plasticity is that property of a body by virtue of which it retains a fraction of its deformation after reduction of the deforming stress to zero.

Elasticity is that property of a body by virtue of which it recovers its original size and shape after deformation.

A material, solid or liquid, may exhibit **Thixotropy,** that is, the form of its rheological curve (rate of shear vs. shearing stress) may depend on the previous extent and duration of shearing deformation. Such thixotropic materials are usually of the complex liquid or the plastico-viscous solid types. The action of shearing a thixotropic material results in reducing the shearing stress necessary for a given rate of shear.

Some materials, notably those of the elastico-plastic type, exhibit an effect known as **Strain Hardening,** which is, in a sense, the inverse of thixotropy, i. e., yield stress increases with increasingly shearing strain.

Materials for which the stress-strain curve obtained with increasing stress does not coincide with the curve obtained with decreasing strain are said to exhibit **Hysteresis** and are known as **Hysteretics.** Elastic solids show no hysteresis whereas all other types of solids show it in varying amounts. The classification "hysteretic" is most useful with regard to materials which are predominantly elastic; i.e., elastico-plastic and elastico-viscous solids.

Quantitative Definitions:

From an analytical point of view, the simplest type of deformation without volume change is the simple shear. It is convenient and logical, therefore, to take the simple shear as the basic type of deformation and to base upon it our definitions of the primary quantitative rheological properties. This policy seems justified from a practical standpoint also since all the analytically more complex but experimentally simpler types of deformations can be resolved into simple shears. A simple shear is a deformation in which the material at any point has moved parallel to a fixed line in a reference plane by an amount which is proportional to the distance of the point from the plane. Such a deformation is shown in Figure 1, the full lines showing the initial shape and the dotted lines the final shape. OO is the fixed line in the reference plane, P is the original position of a point in the body, and P′ its position after deformation. The extent of the shear or shearing strain, ε , is determined by the ratio of the displacement, ds, to the distance, dr of the point, P, from OO. Thus ε = ds/dr. The angle α is known as the angle of shear ($\alpha = \tan^{-1}$ ds/dr). If the shear is continuous the rate of shear (dv/dr) is simply the time rate of change of the quotient ds/dr.

Complex shears are possible, involving two or more simple shears taking place simultaneously in three orthogonal surfaces; but they need not be considered for present purposes, and in what follows, the word "shear" is to be taken as signifying a simple shear only.

The **Consistency** of a material is the ratio of the shearing stress to the rate of shear.

The **Viscosity** of a simple liquid is the constant ratio of shearing stress to the rate of shear. The unit of viscosity in the C.G.S. is called the **Poise.**

The term "viscosity" is applied only to simple liquids. However, the adjective "viscous" is not so limited in its application; and it will be noted in the definitions given above that the terms "elastico-viscous" and "plastico-viscous" are not limited to materials with a straight-line rheological diagram.

The **Fluidity** of a simple liquid is the reciprocal of the viscosity. The unit of fluidity in the C.G.S. system is called the **Rhe.**

In the special case where the rate of shear is a linear function of the shearing stress with a positive intercept on the stress axis, the **Mobility** μ may be defined by the equation:

$$\frac{dv}{dr} = \mu\,(F - F_0)$$

where dv/dr is the rate of shear, F_0 is the yield stress, and F is the shearing stress.

The **Elastic Limit In Shear** of a solid is the maximum deformation that is elastic and is the minimum deformation that results in rupture, or in a permanent shear deformation.

The **Shear Strength** of a solid is the minimum value of the shearing stress at which macroscopic rupture occurs.

The **Shear Modulus of Elasticity** (modulus of rigidity) of an elastic solid is the constant ratio of shearing stress to shear strain for values of the shear strain below the elastic limit in shear.

Rheological Diagram

It is recommended that, wherever possible, published data on complex liquids should include not only the directly observed quantities such as pressure, time of efflux, etc.; but, in addition, the calculated basic quantities. The preferred curve should be either consistency, fluidity, or rate of shear plotted against shearing stress; rather than efflux rate against pressure or rate of rotation against torque. **Rheological Curve** or **Rheological Diagram** are suggested as short convenient terms for curves of these preferred types.

Summary Of Rheological Nomenclature

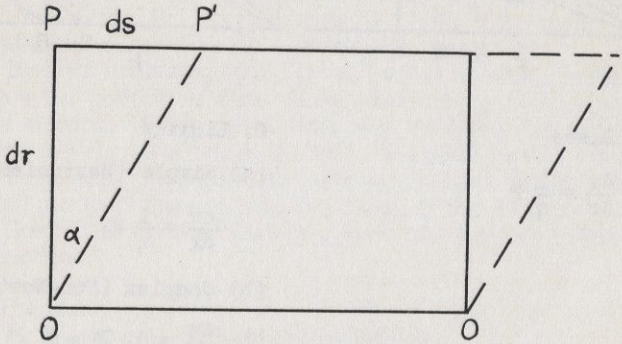
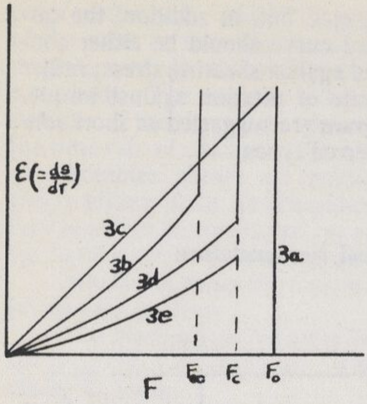
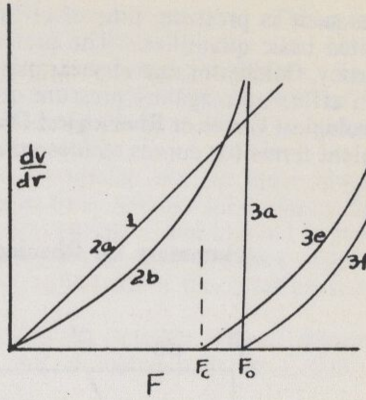


Figure 1 Simple Shear

s : Linear displacement parallel to direction of deformation.
r : Linear coordinate in the plane of the deformation and normal to direction to deformation.
ds/dt : linear velocity.
dv/dr : Rate of Shear.
F : Shearing stress.
$\varepsilon =$ ds/dr : shear strain.
F_c : Critical shearing stress at elastic limit in shear.
F_o : Yield stress.
F_∞ : Shearing stress at rupture (shear strength).
η : Coefficient of viscosity.
G : Shear modulus of elasticity (modulus of rigidity)
μ : Coefficient of mobility.
$F/\frac{dv}{dr}$: Consistency.





1. Gases

$$\frac{dv}{dr} = \frac{1}{\eta} F$$

2. Liquids

(a) Simple (Newtonian)

$$\frac{dv}{dr} = \frac{1}{\eta} F$$

(b) Complex (Non-Newtonian)

$$\frac{dv}{dr} > 0, \; F > 0$$

3. Solids

(a) Plastic

$$\varepsilon = 0, \; 0 < F < F_o$$

$$\varepsilon > 0, \; \frac{dv}{dr} > 0, \; F = F_o$$

(b) Elastic

$$\varepsilon = f(F) > 0, \; 0 < F < F_\infty$$

(c) Hookian

$$\varepsilon = \frac{1}{G} F, \; 0 < F < F_\infty$$

(d) Elastico-Plastic

$$\varepsilon = f(F) > 0, \; 0 < F < F_c$$

$$\varepsilon > 0, \; \frac{dv}{dr} > 0, \; F = F_c$$

(e) Elastico-Viscous

$$\varepsilon = f(F) > 0, \; 0 < F < F_c$$

$$\varepsilon > 0, \; \frac{dv}{dr} > 0, \; F > F_c$$

(f) Plastico-Viscous

$$\varepsilon = 0, \; 0 < F < F_o$$

$$\varepsilon > 0, \; \frac{dv}{dr} > 0, \; F > F_o$$

REPORT OF COMMITTEE ON NOMINATIONS

The Constitution of the Society provides that officers shall be elected biannually by a letter ballot of the membership. The By-laws provide that candidates be nominated by a nominating committee appointed by the president, and that these nominations be published nine months in advance of the election.

The next election will take place in advance of the annual meeting for 1937, which will be held probably in October. At the last meeting, President Mooney appointed a nominating committee consisting of Miss Cobb, Dr. Sheppard and Dr. Lillie, Chairman. The list of candidates prepared by this committee is given below.

The By-laws further provide that additional nominations be received upon the petition of three active members up to six months before the election. Such nominations will, therefore, be accepted by the secretary for inclusion in the ballot if mailed to him prior to May 1st of this year. In accordance with the By-laws, ballots will be mailed to all members three months in advance of the election.

The Committee on Nominations submits the following slate for the 1937 election:

For President:
M. Mooney, U. S. Rubber Products, Inc.

For Vice Presidents: (Vote for Two. Candidates receiving highest and second highest number of votes to be first and second vice presidents, respectively):
A. S. Hunter, duPont Company
E. C. Bingham, Lafayette College
W. H. Herschel, Bureau of Standards
J. H. Dillon, Firestone Tire & Rubber Company

For Editors: (Vote for Two. Editor and Associate Editor to be chosen as above):
W. P. Davey, Pennsylvania State College
E. O. Kraemer, duPont Company
W. H. Fulweiler, Wallingford, Pa.
R. N. Traxler, Barber Asphalt

For Secretary-Treasurer:
R. L. Peek, Jr., Bell Telephone Laboratories.

Committee on Nominations,

H. R. LILLIE, Chairman.

THE SOCIETY OF RHEOLOGY

The Society of Rheology was founded in 1929 to further the study of the deformation and flow of matter. This purpose has been interpreted in the broadest sense, as covering types of deformation ranging from the viscous flow of fluids, through the plastic flow of soft substances, to the elastic deformation of solids. Rheology may be regarded as the science whose industrial application constitutes the field of materials testing.

Papers dealing with Rheology are presented to the Society at its annual meetings, and are published in the Journal of Applied Physics. All members of the Society receive the Rheology Leaflet, which is issued at irregular intervals, and which tells who is who and what is what in Rheology. They receive additional publications according to their class of membership, as indicated on the application blank appearing on the page following.

Membership is for the calendar year and new members receive the issues of the journal published prior to their applications. After September 1, application may be made, if desired, for membership to start January 1 of the year following.

The Society of Rheology is one of the member societies of the American Institute of Physics, and its members are entitled to subscribe to the following additional journals published by the Institute, at the rates shown:

	Domestic	Foreign
Physical Review	$15.00	$16.50
Reviews of Modern Physics	3.00	3.40
Journal of the Optical Society of America	6.00	6.60
Review of Scientific Instruments	1.50	2.00
Journal of the Acoustical Society of America	6.00	6.60
Journal of Chemical Physics	10.00	11.00
American Physics Teacher	3.00	3.30

APPLICATION

Mr. R. L. Peek, Jr., Secretary
The Society of Rheology
Bell Telephone Laboratories, Inc.
463 West Street
New York, New York

I hereby apply for membership in the Society of Rheology for the year ________________ as follows:

[ ] Sustaining membership (including subscriptions to both **Journal of Applied Physics** and **R. S. I.** $25.00 or more

[ ] Regular membership (including subscription to **Journal of Applied Physics)** $6.00 (foreign, $6.50)

[ ] Associate membership (including subscription to **Review of Scientific Instruments)** $2.50 (foreign, $3.00)

Please also enter my subscription for the following additional periodicals published by the American Institute of Physics:

____ at $ ____________________

____ at $ ____________________

____ at $ ____________________

I enclose $____________ to cover the above.

(Please print)

(Name) ____

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(Title)

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(Corporation or School)

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(No.) (Street)

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(City and State)