NATIONAL BUREAU OF STANDARDS REPORT

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INTERLABORATORY TESTS ON
GLASS YARN REINFORCED PAPER

by

Emanuel Horowitz, Russell J. Capott
and John Mandel

to

Post Office Department
Office of Research and Engineering
Washington 25, D. C.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Interlaboratory Tests on Glass Yarn Reinforced Paper

Emanuel Horowitz, Russell J. Capott
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SUMMARY

The results of an interlaboratory study of the test methods developed to determine the physical properties of glass yarn reinforced paper are reported in this paper. For the breaking strength test the pooled standard deviation of Laboratories A and B [1/] based on a **single** measurement was as follows:

Dry Test - Machine direction 6.6 lb/in
Cross direction 6.1 lb/in
Wet Test-Machine direction 3.2 lb/in
Cross direction 2.8 lb/in

The pooled standard deviation for the breaking strength test at the crease was 4.7. In the seam strength test the pooled standard deviation was 2.6 for the dry condition and 1.8 for the wet condition. Finally, in the cross direction yarn pull-out test the pooled standard deviation was 0.8.

The average results of the three laboratories differed by as much as 10 percent in the dry breaking strength and 30 percent in the wet breaking strength. For the breaking strength at the crease the average results of the participants were in good agreement and

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1/ Laboratory C was not included because their equipment did not permit testing 1 inch specimens and 40 specimens 0.5 inches wide were used.

differed by about 2 percent. In the dry seam strength test the difference between the laboratories, based on averages, was approximately 4 percent; while for the wet seam strength test the difference was as much as 18 percent. The average values for the cross direction glass yarn pull-out test were appreciably different (Laboratory A 6.6 lbs, Laboratory B 5.6 lbs, and Laboratory C 7.2 lbs). Certain deviations from the prescribed test procedures did occur in the course of this study and these may have contributed to the variability between different laboratories. For example Laboratory A used a pendulum type tensile tester while the results reported for Laboratory B were obtained with an inertialess type tester. In addition, Laboratory C, because of the nature of its equipment, used tests specimens having width dimensions different from that specified in the test procedure.

In the breaking strength test the average value was about 68 lb/in width in the machine direction and about 44 lb/in width in the cross direction and the strength in each direction was reduced by approximately 50 percent after being wetted with water. The overall average results obtained for the breaking strength at the crease and the dry seam strength were very similar, about 39 lb/in width. The lowest values were reported for the wet seam strength, approximately 9 lb/in width; a reduction of 75 percent as compared to the dry condition.

1.0 INTRODUCTION

As a result of an earlier study, National Bureau of Standards Report 6467, a number of test methods for determining the physical properties of glass yarn reinforced paper used in fabricating mail bags were developed or modified. At the request of the Post Office Department an interlaboratory test was arranged among three laboratories concerned with determining the physical properties of this paper in order to obtain information on the precision of the test methods. The three laboratories included two industrial laboratories and the National Bureau of Standards.

For each of the tests in this study, specimens were prepared from fifteen different glass yarn reinforced paper mail bags taken from one production lot. The specimens were carefully randomized and distributed among the three laboratories to be tested for the following properties:

1. Breaking Strength: Machine and Cross Direction, Wet and Dry
2. Breaking Strength at Crease
3. Seam Strength; Wet and Dry
4. Cross Direction Glass Yarn Pull-out Resistance

This report discusses the test methods used in determining the physical properties of the reinforced paper and the results of the statistical analysis of the test data.

2.0 PHYSICAL TEST METHODS

The following instructions were sent to the participating laboratories for conducting the tests:

2.1 Breaking Strength Test, Dry

The specimen for test shall be strips 1 inch wide and 8 inches long with the edges cut parallel to each other and to the reinforcing yarn. Each specimen shall have two reinforcing yarns extending the length of the specimen. The distance between each yarn and the nearest edge of the specimen shall be approximately 1/4 inch.

The test shall be made on a pendulum type machine 2/ having two clamps whose centers shall be in the same plane parallel with the direction of motion of the stressing clamp and so aligned that they will hold the test specimen wholly in one plane. The machine shall apply a gradually increasing load to the specimen until it breaks and shall indicate the load at the instant of fracture.

The tester shall be of such capacity that the breaking strength of the specimen will be not greater than 90 percent nor less than 10 percent of the capacity of the tester.

The initial separation between the clamps shall be 4 inches. The specimen shall be firmly clamped squarely in the jaws of the clamps and the stressing jaw operated at a speed of 12 ± 0.5 inches per minute until the specimen breaks. For each test specimen the breaking load shall be recorded to the nearest 0.1 pound per inch of width. Twenty specimens, with the long dimension cut parallel to each principal direction of the paper, shall be tested and the average of the test results for each principal direction shall be reported to the nearest 0.1 pound per inch of width. All readings obtained when the paper breaks at or in the jaws shall be rejected and another specimen shall be tested. Test results of strips cut in the machine direction of the paper shall be reported as breaking strength per inch of width, machine direction and test results of strips cut across the machine direction shall be reported as breaking strength per inch of width, cross direction.

In the course of this study the tests made by the National Bureau of Standards were performed on a pendulum type tensile tester using the procedure described above. The tests in Laboratory B were made with an inertialess type tensile tester [a] with a

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2/ Tests may be made on a tensile tester which has been shown to give equivalent results to those obtained with a pendulum type machine.

(a) Table Model Instron Tester

rate of jaw separation of 1 inch per minute. The tests made by Laboratory C were made with a pendulum type tensile tester using 0.5 inch wide specimens in the breaking strength test because 1 inch clamps were not available. In addition, because of the type of equipment available, the seam strength and breaking strength at the crease tests were made on a pendulum type machine using 1 inch wide specimens instead of 2 inch wide specimens. The effect of these deviations in test procedures on the test results will be discussed later in this report.

2.2 Breaking Strength Test, Wet

The procedure described for the dry breaking strength (2.1) shall be followed, except that the specimen shall be immersed in 1 to 2 inches of distilled water for 2 hours at 23°C ± 2°C (73.4°F ± 3.6°F) before testing. The specimen shall be taken from the water, the excess water removed with blotting paper and the specimen tested within 60 seconds. If weights are used to keep the specimen immersed, that part of the specimen to be positioned between the upper and lower clamps shall be untouched by the weights. Specimens shall not be placed on top of each other in the water bath.

2.3 Breaking Strength at Crease

The test shall be made in accordance with the procedure described in Section 2.1 except that the crease shall be midway between the ends of the specimen and perpendicular to the long dimension. The specimen shall be taken at random from any of the longitudinal creases produced during the manufacture of the mail sack.

2.4 Seam Strength Test, Dry

The specimen shall be 2 inches wide and 8 inches long with the long dimension cut at right angles to the seam. The two sections of paper forming the seam shall each contain four cross direction glass yarns with the distance between the end yarns and the nearest edge of the specimen approximately 1/4 inch. The seam shall be located midway between the two ends of the test specimen. The specimen shall be mounted in the jaws of the tensile tester referenced in Section 2.1 with the seam perpendicular to the direction of motion of the stressing clamp. The initial separation between the clamps shall be 4 inches. For each specimen the force required to cause seam separation shall be recorded to the nearest 0.1 pound. Twenty test specimens shall be tested and the average of the values obtained shall be reported to the nearest 0.1 lb/in. All readings obtained when the paper breaks at or in the jaws shall be rejected and another test specimen shall be tested.

2.5 Seam Strength Test, Wet

The procedure described for dry seam strength shall be followed, except that the specimen shall be immersed in distilled water as described in the wet breaking strength test, Section 2.2.

2.6 Cross Direction Glass Yarn Pull-out Test

The specimen shall be one inch wide and 10 inches long with the long dimension parallel to the cross direction glass yarn. A single cross direction glass yarn shall be located in the center of the specimen approximately parallel to the two edges. Two inches from one end of the specimen a hole 3/16 inch in diameter shall be punched through the paper and cross direction glass yarn with a paper punch. Two inches from the opposite end of the specimen a cut perpendicular to the cross direction glass yarn shall be made from each edge of the specimen to the cross direction glass yarn. Twelve machine direction glass yarns shall be located in the 6 inches between the punched hole and the slits. Care shall be exercised not to damage the glass yarn. The specimen shall be tested on the tensile tester referenced in Section 2.1. The initial separation between the clamps shall be 7 inches, and no part of the punched hole or the slit shall be clamped between the jaw surfaces. For each specimen the force required to pull-out the glass yarn shall be recorded to the nearest 0.1 pound. Twenty specimens shall be tested and the average of the values obtained for the test unit shall be reported to the nearest 0.1 pound.

3.0 DISCUSSION OF RESULTS

3.1 Breaking Strength

Tables 1 and 2, list the individual values for dry and wet breaking strength respectively, and indicate that considerable variability exists between specimens tested in the same laboratory. Thus, based on 20 determinations, the difference between the highest and lowest test result in the dry condition was about 23 lb/in width and about 13 lb/in width in the wet condition. Also, it can be seen that the average results reported by the three laboratories for dry breaking strength differ by 7.6 lb/in width in the machine direction and 2.3 lb/in width in the cross direction. In the wet breaking strength tests the averages reported by two of the laboratories differed by 10.2 lb/in width in the machine direction and 5.0 lb/in width in the cross direction. For Laboratories A, B and C the standard deviation of a single measurement in the dry and wet breaking strength tests are given in Table 6. It can be seen that in the dry breaking strength test the standard deviations for Laboratories A, B and C were approximately 5.0, 7.5 and 8.5, respectively. In the wet test the standard deviations ranged from 2.2 to 5.5.

It has been reported in the literature (1) that for specimens 1, 2 and 3 inches in width the breaking strength of paper in lb/in width remained almost constant but when the test specimens were approximately 1/2 inch in width or less there was a marked decrease in the breaking strength with decreasing width. It will be recalled that because of available equipment the specimens tested by Laboratory C were 1/2 inch in width instead of the prescribed 1 inch. Nevertheless, only in the dry machine direction test was the average result lower than those obtained by the other two laboratories. Even in this case it differed by only 7 percent from Laboratory B. On the other hand, the results obtained by Laboratory C in the wet breaking strength test, machine and cross direction, were higher than those of the other two participants. It appears that the effect of width discussed above was not a significant factor in these tests. Furthermore, the breaking strength of the test specimens used in the present study was influenced markedly by the reinforcing glass fibers.

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(1) Institute of Paper Industry Report No. 24, February 16, 1940.

It is also interesting to note that except for the dry machine direction, the breaking strength results reported by Laboratory B (using an inertialess type tensile tester) were somewhat lower than those obtained in the other two laboratories.

3.2 Breaking Strength at Crease

The results for the breaking strength at the crease are reported in Table 3 where it can be seen that the laboratory averages of 38.7, 38.4 and 39.0 lb/in width for Laboratories A, B and C are in good agreement. The difference between the highest and lowest test results within a given laboratory was approximately 20.8, 16.6 and 26.9 lb/in width for Laboratories A, B and C, respectively. The standard deviation of a single measurement, given in Table 6, was 5.1 for Laboratory A; 4.3 for Laboratory B and 5.1 for Laboratory C, showing approximately equal precision in the three laboratories.

3.3 Seam Strength

The average results given in Table 4 for Laboratory A, B and C were 39.9, 38.4 and 38.3 lb/in width, respectively in the dry condition and 9.7, 8.2 and 9.2 lb/in width, respectively, in the wet condition. Within a given laboratory, the difference between the highest and the lowest test result was about 11 lb/in width and 2.5 lb/in width in the dry and wet tests, respectively. Table 6 gives the standard deviation of a single measurement and indicates about the same precision for the three laboratories.

3.4 Cross Direction Glass Yarn Pull-out Resistance

The results obtained in the glass yarn pull-out test are given in Table 5. The average values for Laboratory A, B and C based on 20 determinations, were 6.6 lb, 5.6 lb, and 7.2 lb, respectively. Thus the results for at least two of the laboratories differed by about 30 percent. Within a given laboratory the difference between the highest and lowest test results were 1.4 lb, 2.0 lb, and 3.4 lb, accounting for differences of about 25 to 45 percent. The standard deviation of a single measurement given in Table 6 was 0.97 (Laboratory A), 0.62 (Laboratory B), and 0.71 (Laboratory C), showing good precision for this measurement among the participants.

3.5 Effect of Water on the Strength

The results reported in Table 6 show that the strength of the material is markedly decreased when wetted with water. In the breaking strength test the strength of the material decreases from about 50 to 68 percent in the machine direction and from about 43 to 54 percent in the cross direction. A most pronounced decrease in the seam strength occurred as a result of immersion in water. In fact the wet strength was only approximately 9 lb/in width, having decreased in strength by about 75 percent. The effect of water on the strength of the material may be seen in greater detail by examining Table 7.

Table 1. Dry Breaking Strength, lb/in Width

Machine Direction					Cross Direction			
Spec. No.	Lab. A a/	Lab. B b/	Lab. C c/		Lab. A	Lab. B	Lab. C	
1	74.0	65.0	52.8	68.8	49.0	45.8	52.0	38.4
2	81.8	73.2	78.8	80.4	47.0	35.0	32.0	40.8
3	72.0	65.4	65.2	62.4	48.3	48.4	56.4	41.6
4	72.7	60.5	52.4	64.0	46.0	39.6	44.8	35.2
5	75.5	65.0	66.0	74.8	54.3	30.3	27.2	44.8
6	71.0	72.0	61.2	60.0	48.0	45.7	36.0	51.2
7	58.3	62.9	60.0	68.0	45.0	43.7	51.2	46.4
8	66.2	76.0	62.0	47.6	41.0	51.0	51.2	34.4
9	71.5	75.7	74.4	62.0	47.5	48.7	35.2	31.2
10	74.5	83.7	54.4	44.8	42.0	28.0	60.4	50.4
11	69.9	68.8	60.4	73.2	45.3	48.9	35.2	44.8
12	70.0	73.6	68.8	60.8	44.0	53.9	37.6	40.0
13	67.0	68.0	69.6	66.8	40.0	50.9	37.2	32.8
14	77.3	69.5	66.0	48.8	41.0	48.1	40.0	44.0
15	64.5	66.5	72.0	63.2	51.5	43.7	55.6	47.2
16	70.0	70.7	77.2	62.4	36.0	47.4	47.2	54.8
17	76.0	64.1	65.2	52.8	48.5	38.5	51.2	42.0
18	71.0	63.3	69.2	66.8	44.2	43.1	51.2	36.0
19	72.0	65.9	72.0	49.6	47.0	43.0	44.8	42.0
20	79.8	65.1	70.0	74.4	43.5	38.4	50.4	59.2
Avg.	71.8	68.7	64.2		45.4	43.1	43.8	
High	81.8	83.7	80.4		54.3	53.9	60.4	
Low	58.3	60.5	44.8		36.0	28.0	37.2	
Diff.	23.5	23.2	35.6		18.3	25.9	23.2	

Note: Forty test results are reported by Mosinee because two 0.5 in wide specimens were prepared from the original 1 in wide specimens furnished. This laboratory had 0.5 in wide clamps instead of the 1 in wide clamp specified in the test procedure.

a/ National Bureau of Standards

b/ Bemis Bros. Bag Company

c/ Mosinee Paper Mills Company

Table 2. Wet Breaking Strength, lb/in width

Machine Direction					Cross Direction			
Spec. No.	Lab. A a/	Lab. B b/	Lab. C c/		Lab. A	Lab. B	Lab. C	
1	23.3	23.0	24.8	38.4	23.7	20.3	24.0	23.2
2	26.3	28.2	33.6	34.0	22.0	17.6	28.8	28.8
3	27.5	24.5	30.4	39.2	17.4	18.8	31.2	22.4
4	26.7	17.4	30.4	32.0	20.9	17.8	31.2	20.0
5	26.6	20.6	30.4	36.8	26.0	20.4	28.0	20.0
6	26.9	25.0	31.2	32.0	21.5	20.4	22.4	27.6
7	25.4	25.7	32.0	36.0	19.1	25.0	30.8	28.0
8	28.7	16.0	16.0	34.4	25.0	23.8	18.8	28.0
9	21.3	22.0	31.2	40.0	20.0	21.0	25.2	23.2
10	27.9	20.4	27.2	32.8	25.3	18.8	28.8	23.2
11	25.7	18.0	29.2	40.0	25.7	22.0	28.0	22.4
12	22.6	19.5	24.0	34.8	25.6	17.9	26.0	22.0
13	30.3	23.5	27.2	26.4	24.2	18.0	22.8	24.0
14	23.7	19.2	34.0	35.2	24.4	19.5	26.8	19.2
15	27.3	22.8	24.8	28.0	23.3	21.0	24.8	24.0
16	22.5	23.8	34.4	38.4	22.8	22.2	24.0	31.2
17	22.0	22.7	22.0	34.4	15.2	21.5	22.0	19.2
18	28.7	21.8	40.0	36.0	22.9	18.3	24.0	32.0
19	25.1	25.6	36.8	28.0	15.0	19.2	23.2	23.2
20	38.3	23.2	38.0	39.2	20.5	16.9	28.8	20.8
Avg.	26.2	22.1	32.3		22.0	20.0	25.0	
High	35.3	28.2	40.0		26.0	25.0	32.0	
Low	21.3	16.0	16.0		15.0	16.9	18.8	
Diff.	14.0	12.2	24.0		11.0	8.1	13.2	

Table 3. Breaking Strength at the Crease, lb/in width

Specimen Number	Laboratory A	Laboratory B	Laboratory 1/ C	
1	46.7	43.0	36.0	44.7
2	45.0	28.2	38.9	32.6
3	25.9	38.4	38.5	37.9
4	34.0	44.8	32.3	34.0
5	37.1	43.5	44.5	43.2
6	37.9	44.5	38.5	38.4
7	32.7	39.2	38.6	31.7
8	44.5	37.8	20.6	42.3
9	35.0	38.8	46.7	39.9
10	43.0	38.0	40.8	43.4
11	40.0	36.5	42.5	33.1
12	38.5	37.8	36.7	37.7
13	38.1	39.5	38.1	43.7
14	37.9	40.7	39.2	38.2
15	36.9	30.0	36.5	47.5
16	41.0	37.0	38.6	43.0
17	33.5	36.6	46.8	41.9
18	38.5	33.8	31.6	38.0
19	41.0	42.8	44.9	39.9
20	45.9	37.8	41.7	38.3
Avg.	38.7	38.4	39.0	
High	46.7	44.8	47.5	
Low	25.9	28.2	20.6	
Diff.	20.8	16.6	26.9	

1/ Due to the equipment available the original specimens were cut into two specimens and forty tests were made.

Table 4. Seam Strength, lb/in width

	DRY				WET			
Spec. No.	Lab. A	Lab. B	Laboratory C		Lab. A	Lab. B	Laboratory C	
1	40.0	32.2	38.0	43.1	9.4	9.2	10.9	9.5
2	40.6	39.0	39.5	38.5	8.8	8.0	8.8	9.0
3	40.0	39.0	30.8	38.4	10.3	8.6	9.1	10.2
4	33.2	28.6	40.1	31.3	10.3	8.7	10.7	7.9
5	43.2	37.5	43.1	38.1	8.8	8.0	8.8	9.6
6	41.4	41.0	39.6	40.4	10.4	8.9	9.8	8.7
7	38.2	40.2	41.5	38.8	9.6	7.7	8.5	9.7
8	42.6	39.2	41.3	37.5	9.7	8.2	9.2	8.3
9	41.5	39.6	39.0	34.5	10.1	8.0	9.3	9.1
10	38.5	32.5	39.5	38.6	10.8	7.1	10.0	9.2
11	41.6	38.4	39.9	41.3	10.4	8.1	8.6	8.7
12	42.0	41.0	44.5	33.4	8.5	7.7	9.6	9.3
13	41.0	38.0	39.7	33.1	9.5	8.3	8.6	10.0
14	42.5	38.9	39.9	37.0	9.6	7.7	9.4	9.1
15	34.2	39.6	37.4	36.3	9.7	8.6	7.9	8.3
16	40.4	37.2	37.4	38.3	10.2	8.1	8.8	9.3
17	38.8	40.8	36.0	39.3	9.4	8.6	10.0	8.8
18	40.5	39.2	39.7	45.0	9.2	8.7	8.5	9.3
19	37.6	40.6	39.4	40.1	9.8	8.0	10.0	8.8
20	39.9	35.5	32.7	30.4	9.1	8.8	10.0	8.0
Avg.	39.9	38.4	38.3		9.7	8.2	9.2	
High	43.2	41.0	45.0		10.8	9.2	10.9	
Low	33.2	32.2	30.4		8.5	7.1	7.9	
Diff.	10.0	8.8	14.6		2.3	2.1	3.0	

Table 5. Cross Direction Glass Yarn Pull-out Resistance, lb

Specimen Number	Laboratory A	Laboratory B	Laboratory C
1	6.2	5.3	6.8
2	6.4	6.7	7.6
3	6.6	5.5	7.0
4	6.6	4.9	7.2
5	7.2	4.8	7.4
6	6.8	5.2	5.0
7	6.0	5.7	7.4
8	7.4	6.5	7.2
9	7.1	4.9	7.6
10	6.1	4.7	8.4
11	7.4	6.2	7.2
12	7.2	6.2	7.2
13	6.0	5.7	7.6
14	6.0	5.1	8.2
15	6.2	6.0	6.4
16	6.6	6.6	6.8
17	6.6	5.1	7.4
18	6.5	5.4	7.4
19	7.1	5.8	6.9
20	7.2	5.4	7.0
Avg.	6.6	5.6	7.2
High	7.4	6.7	8.4
Low	6.0	4.7	5.0
Diff.	1.4	2.0	3.4

Table 6. Summary of Test Results

	Laboratory A		Laboratory B		Laboratory C 2/	
	Avg.	σ 1/	Avg.	σ	Avg.	σ
Breaking Strength, lb/in width						
DRY						
Mach. Direction	71.8	5.3	68.7	7.6	64.2	8.8
Cross Direction	45.4	4.2	43.1	7.5	43.8	8.3
WET						
Mach. Direction	26.2	3.3	22.1	3.1	32.3	5.5
Cross Direction	22.0	3.3	20.0	2.2	25.0	3.7
Breaking Strength, Crease, lb/in width	38.7	5.1	38.4	4.3	39.0	5.1
Seam Strength, lb/in width						
DRY	39.9	2.6	38.4	2.5	38.3	3.4
WET	9.7	2.0	8.2	1.6	9.2	0.7
Cross Direction Yarn Pull-out, lb	6.6	0.97	5.6	0.62	7.2	0.71

1/ Standard deviation of a single measurement

2/ For Laboratory C, all but the yarn pull-out data are based on 40 measurements.

Table 7. The Effect of Water on the Strength of the Material

	Laboratory A	Laboratory B	Laboratory C
Breaking Strength, lb/in width			
Machine Direction			
Dry	71.8	68.7	64.2
Wet	26.2	22.1	32.3
% Decrease	63.5	67.8	49.7
Cross Direction			
Dry	45.4	43.1	43.8
Wet	22.0	20.0	25.0
% Decrease	51.5	53.6	42.9
Seam Strength, lb/in width			
Dry	39.9	38.4	38.3
Wet	9.7	8.2	9.2
% Decrease	75.7	78.6	76.0

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Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation. • Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

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