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Woodrow Wilson Memorial Bridge over the Potomac River connects Virginia and Maryland. An important link in the Capital Beltway, this bridge provides access to the District of Columbia from the south.

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Comparison of Two Methods for Preloading Electronic Scales

By **RUSSELL E. PUCKETT**, Assistant Professor
of Electrical Engineering, and **JAMES E. GOVER**,
Research Assistant in Instrumentation,
University of Kentucky [1]

Introduction

ELECTRONIC scales are a relatively new addition to the types of tools used by the highway engineer. Many agencies concerned with planning and maintenance of adequate systems of highways have established and evaluated different methods for obtaining load data. The electronic scale has attracted considerable attention because electronic measuring techniques permit the solution of many problems related to weighing moving vehicles. Many systems have been developed in which electronic techniques are used to measure and record both static and dynamic loads. Some advantages of the electronic systems, as opposed to mechanical scales, are the sensitivity that permits detection of extremely small loads and observation of high-speed phenomena, which occur too fast for visual observation, and the small physical spaces required for electronic load detectors [1].[2]

Instrumentation of electronic load-measuring systems serves two purposes; (1) detection of an electric analog of the load being measured and (2) rapid acquisition of a tremendous volume of data and its reduction to summary form for use in quick analysis. Some of the problems inherent in producing an accurate analog of a load being measured with an electronic instrumentation system are discussed in this article. Specifically, data are presented relative to the system being developed and tested by the University of Kentucky in a research project that is sponsored jointly by the U.S. Bureau of Public Roads and the Kentucky Department of Highways. Purpose of this research project is to develop a dependable system for weighing vehicles, particularly trucks, as they roll along the highway [2].

To meet the need for collecting and analyzing large volumes of data requisite to highway planning, highway engineers are using new tools such as electronic weighing systems and other electronic instrumentation systems. This article reports on another phase of a research project on electronic weighing systems. The purpose of such a system is to weigh vehicles in the traffic stream without stopping them or interfering with their travel. In doing this the electronic device must be able to detect and record an electric analog of the load applied to the system, without including variable factors such as the vibration and oscillation of the weighing platform. To achieve stability of the platform, different methods of preloading have been devised. Although these methods of preloading the platform achieve the desired stability, they also reduce the overall sensitivity of the measuring system to imposed loads. This article presents an analysis of two preloading methods and shows their relative effectiveness in maintaining system sensitivity while achieving mechanical stability of the weighing platform.

Conclusions

From an analysis of the two methods of preloading the platform of an electronic weighing device with coil springs and with steel rods, it has been concluded that preloading with coil springs affords better stability and has little effect on the sensitivity of the measuring system.

To achieve maximum benefit from an electronic weighing system, the largest possible output must be obtained. The output analog of the applied load always will be relatively small and anything that reduces or tends to reduce it should be avoided or made as ineffective as possible [3].

This research demonstrated that heavy coil springs, which may be stretched a considerable distance in relation to motion of the weighing platform, afforded stability of the platform while maintaining the overall sensitivity of the measuring system. When steel rods were used for preloading, however, the sensitivity of the system was reduced to an extent that negated the effectiveness of the rods in stabilizing the platform. Therefore preloading a dynamic platform with coil springs is more advantageous than using steel rods for this purpose.

Load Measuring

To record dynamic load data, some means must be provided for detecting the load. A transducer capable of accepting the load data as a mechanical force and converting it to an electric analog may be used in an electronic weighing system. The input to an electronic scale is a physical force proportional to the applied load. The output of the transducer should be an electric analog of the load. Many types of load detectors have been used but the strain gage load cell has been employed in the research reported here. A complete description of the strain gage load cell, the principle of its operation, and the recording instrumentation are detailed in references 2 and 4. The basic construction of a typical load cell is shown in figure 1.

Commercial designs have been developed for electronic weighing systems that use a platform supported at its four corners by load cells; figure 2 shows a typical installation. The platform is set level with the road surface to measure the axle loads of trucks as they roll over it. The output of the load cells is proportional to the weight applied to the platform by the truck wheels [4]. Many problems have been encountered when this type of system has been used to measure the axle load of trucks in motion. The principal problem has been related to leveling the platform on its four supports so as to prevent its tipping and thus causing unbalanced loads on the four load cells. Some degree of success has been obtained in overcoming this problem [4]. By preloading the platform with tension turnbuckles and steel rods, it has been leveled and the tendency for it to oscillate upon application of load has been greatly reduced.

To eliminate horizontal movement of the weighing platform without reducing the sen-

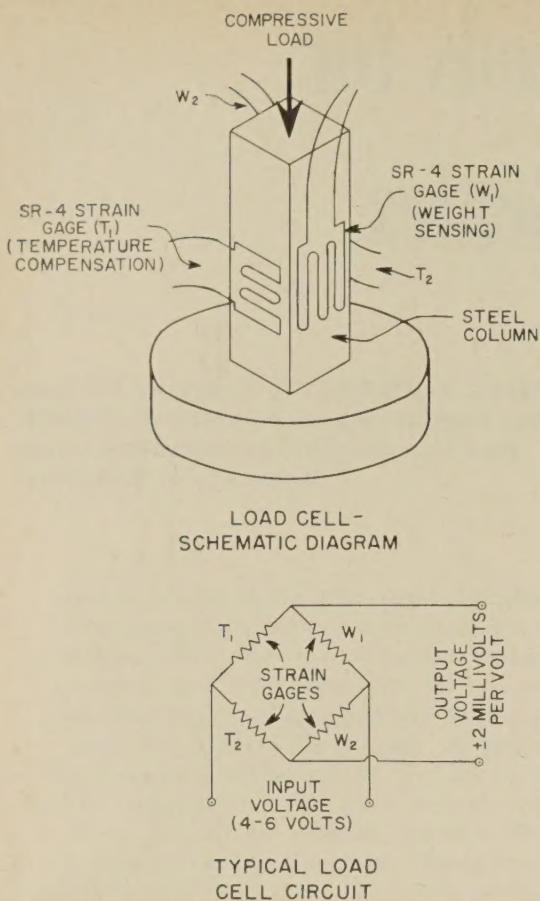Figure 1.—Construction of typical load cell.

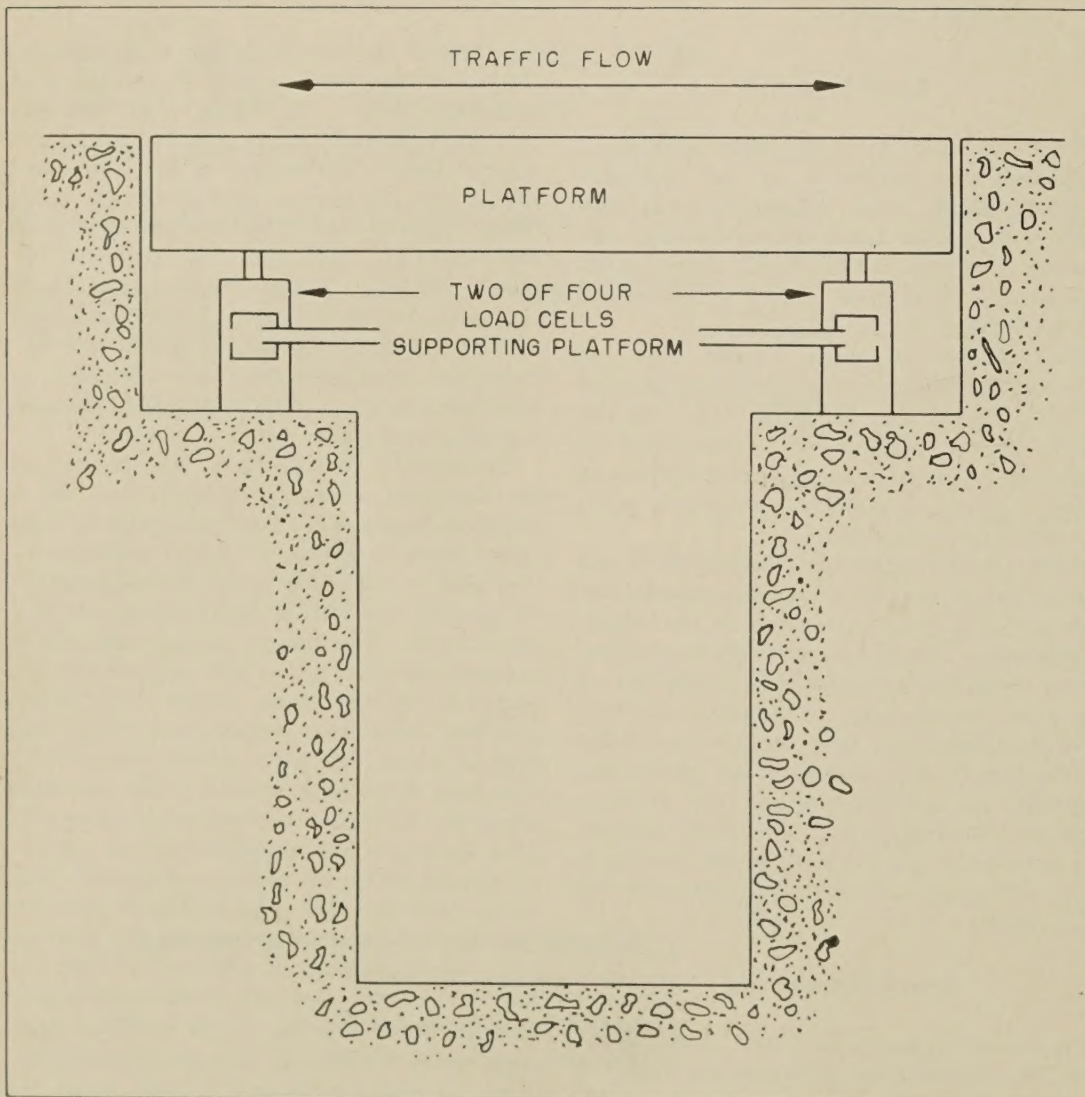LOAD CELL—
SCHEMATIC DIAGRAM

TYPICAL LOAD
CELL CIRCUIT

Figure 2.—Installation of platform supported at four points.

sitivity of the system to vertical loads, the Research Organization for Roadbuilding in West Germany has developed and built a broken-bridge design that is less subject to vibration than the platform supported on four corners. The broken-bridge design is shown in figure 3; this system has two, narrow steel boxes that rest on the foundation of the platform's supporting structure. Load cells that convert the load into an electric analog are located beneath the center joint connecting the halves of the bridge (5, 6).

Platform Used at University of Kentucky

A broken-bridge platform, based on the German design, was developed for the research project at the University of Kentucky and installed on the University's farm for use in different tests of the electronic weighing system. An exterior view of the platform in place at the test site is shown in figure 4. Two types of preloading devices—steel rods and turnbuckles or heavy coil springs—were attached to the platform to stabilize the system to the applications of dynamic loads. Tests were made to determine the performance of the system with each of the preloads. An interior view of the scale pit, including the installation of steel rods and turnbuckles between the platform and the bottom of the scale pit, is illustrated in figure 5. The use of heavy coil springs to preload the weighing device is shown in figure 6.

Both preloading methods reduced platform oscillation under loading. However, the overall sensitivity of the recording instrumentation was reduced more when the steel rods were used for preloading than when the coil springs were used. The output of the load cells supporting the platform was greatly reduced when preloading was accomplished by the steel rods but the output remained practically at its "no-preload" value for any load when the springs were used for preloading the system. The two preloading methods and an analysis of the differences in sensitivity of the system are discussed in detail in the following paragraphs.

Preload Effect on System Sensitivity

The force diagram of figure 7 represents the broken-bridge weighing platform. P_o represents the preload applied to the platform by each of the two preloading members, one at each end of the platform. For this analysis it was assumed that no bending of the platform occurs between the load cells and the points of application of the preload. It was also assumed that a linear relationship of the preloading members exists between their elongation and the force applied. Based on these assumptions, the preload was represented by the expression:

$$P_o = k y_o \tag{1}$$

Where,

P_o = preload
y_o = elongation of preloading members
k = constant of proportionality.

Figure 8 is a force diagram of the platform as it appears when an axle load of $2W$ was applied symmetrically to the platform. Such an application causes compression of the load cells to some distance Δy. Application of the axle load to the platform reduced the tensile force in each of the preloading members by $k\Delta y$. Summation of the vertical forces on the platform showed that the load carried by each load cell may be expressed as:

$$P_1 = P_o - k\Delta y + W \tag{2}$$

Where,

P_1 = load on load cell
P_o = preload
k = constant of proportionality
Δy = distance load cells compressed
W = applied weight (actual load).

When the preload was first applied, the instrumentation was adjusted to its zero position. When an axle load was applied to the platform, the instrumentation indicated an analog of the difference between the initial preload value and the load carried by the load cell. This difference is the value of $P_1 - P_o$ which may be expressed in terms of the distance of compression of the load cell, equation (2), as:
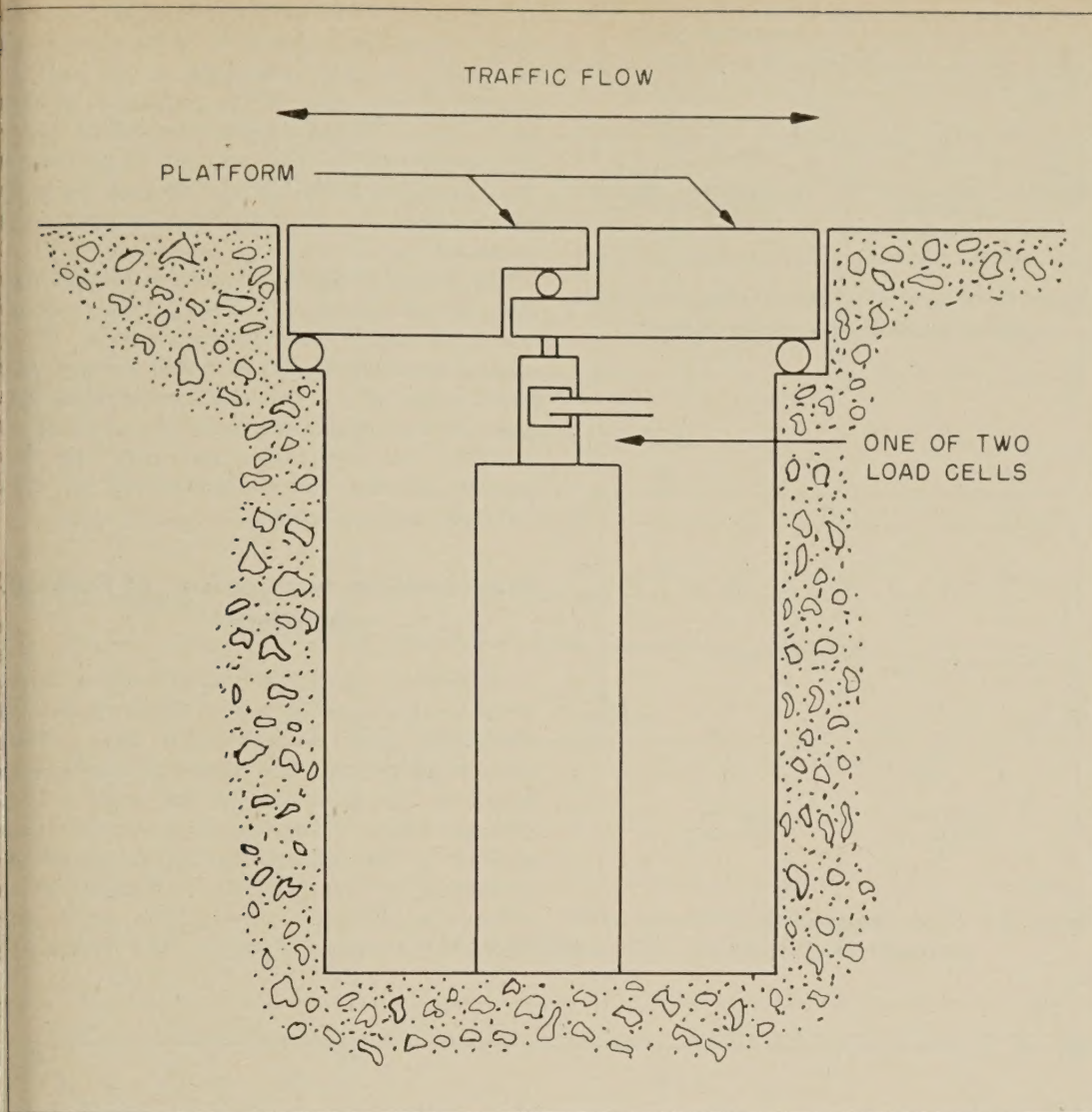
$$P_1 - P_o = W - k\Delta y \tag{3}$$

Figure 3.—Installation of broken-bridge platform.

TRAFFIC FLOW

PLATFORM

ONE OF TWO LOAD CELLS

Equation (3) shows that the analog of the weight indicated on the instrumentation will be in error by $k\Delta y$. Therefore, this factor should be kept as small as possible so that the analog of the applied load will be more nearly representative of the actual load, W. The magnitude of Δy is predetermined by the size of the load applied to the platform and the basic sensitivity of the load cell. For the type of load cell used on this project, Δy was approximately 0.010 inch for a 50,000-pound load. This shows that changes in the value of k are required to increase the overall sensitivity of the system.

Because the initial preload equals ky_o, the value of k must not be made so small that the product ky_o is too small to permit completion of the original purpose of preloading the platform—stabilization of the platform and reduction of vertical oscillation. This requirement suggests use of a device that will allow a large value for y_o and a small value for k, thereby keeping the product $k\Delta y$ small.

Comparison of Methods

Preloading during these tests was achieved in two ways: (1) heavy springs were mounted between the platform and the bottom of the

scale pit, and (2) steel rods were tied to the platform and anchored to the bottom of the scale pit. Both devices were adjustable to permit changing the value of preload. Because of the physical construction of the pit and the platform, both the steel rods and the coil springs were limited in length.

An extension of equation (2) shows the effect of the factor $k\Delta y$ in the two methods of preload. Using equation (1), the effect of the factor may be written as:

$$P_1 = ky_o - k\Delta y + W \qquad (4)$$

or as:

$$P_1 = k(y_o - \Delta y) + W \qquad (4)$$

When the coil springs were used for preloading, the initial elongation of the preload member could be made large in comparison with any compression distance during the application of a load, and can be expressed as:

$$y_o >> y \qquad (5)$$

A "worst case" check may be made for equation (5). Assume that the springs are preloaded at an elongation of 6 inches and that a 25,000-pound axle load is applied to the platform. If the load were placed sym-

metrically on a platform supported by two load cells, each capable of being compressed 0.010 inch at 50,000-pound load, the compression distance of a cell would be:

$$\Delta y = \frac{12,500}{50,000} \times 0.010 \text{ inch} = 0.0025 \text{ inch.}$$

Because y_o equals 6 inches, equation (5) is valid.

When preloading is accomplished by using coil springs, equation (5) may be approximated as:

$$y_o - \Delta y \approx y_o \qquad (6)$$

Based on this approximation, equation (4) may be stated as one or the other of the three following expressions.

$$P_1 = ky_o + W,$$
$$P_1 = P_o + W,$$
$$P_1 - P_o = W.$$

Thus, when coil springs are used for preloading, the applied load can be recorded as an electronic analog that has no serious error caused by the preload. However, when steel rods are used for preloading the platform, the approximation developed in equation (6) is not valid because the characteristics of steel rods prevent their stretching any significant distance. Consideration of equation (4) shows that when steel rods are used for preloading significant error will be reflected in the analog for any load applied to the platform.

Estimating Reduction of Sensitivity

Further manipulation of equation (3) simplifies the comparison of the two methods of preload tested. The load carried by the load cell may be written as:

$$P_1 - P_o = C\Delta y \qquad (7)$$

Where,

C = basic sensitivity of the load cell.

Substitution of equation (7) in equation (3) yields, either

$$P_1 - P_o = W - k\frac{P_1 + P_o}{C}$$

or

$$(P_1 - P_o) = \frac{W}{1 + \dfrac{k}{C}} \qquad (8)$$

Equation (8) is illustrated in figure 9. The slope of the line defining actual sensitivity is

$$\frac{1}{1 + \dfrac{k}{C}}$$

compared with the maximum possible slope of unity when no preload is being used or when $k = 0$.

Equation (8) indicates that the overall sensitivity of the measuring system is reduced by any preload, and the sensitivity depends only upon the method of application of the preload; that is, the value of k. The difference between the load applied and its analog, when no preload was used, is given by the separation

Figure 4.—Broken-bridge scale installed at the test site.

Figure 5.—Steel rods and turnbuckles used for preloading the platform.

Figure 6.—Preloading accomplished with springs.

Figure 7.—Force diagram of platform with initial preload—no load applied.

Figure 8.—Force diagram of platform with preload—load applied.

of the straight line in figure 9. Because the lines are straight, any error of an analog of load will be a fixed percentage of the load it represents, regardless of the magnitude of the load. Also, the error will be dependent upon the magnitude of the preload being used. This reduction of the system's sensitivity will be a constant, provided the value of k remains constant.

The graph of figure 9 has been plotted for only one value each for k and C. Other values would, of course, yield different curves. The separation of the two lines would increase for larger values of k. This again emphasizes the necessity for keeping the value of k as small as possible; the separation represents the reduction of the overall sensitivity of the instrumentation system.

Experimental Comparison of Preload Methods

In order to check the validity of the foregoing analysis of preload methods, a 3-axle truck was used for controlled tests. The amount of preload was based on the static weight of the front axle of this truck. The preload—either coil springs or steel rods—was applied to the platform in increments of 50 percent of the static weight. Weights were recorded at different speeds of the truck and for various amounts of preload that ranged up
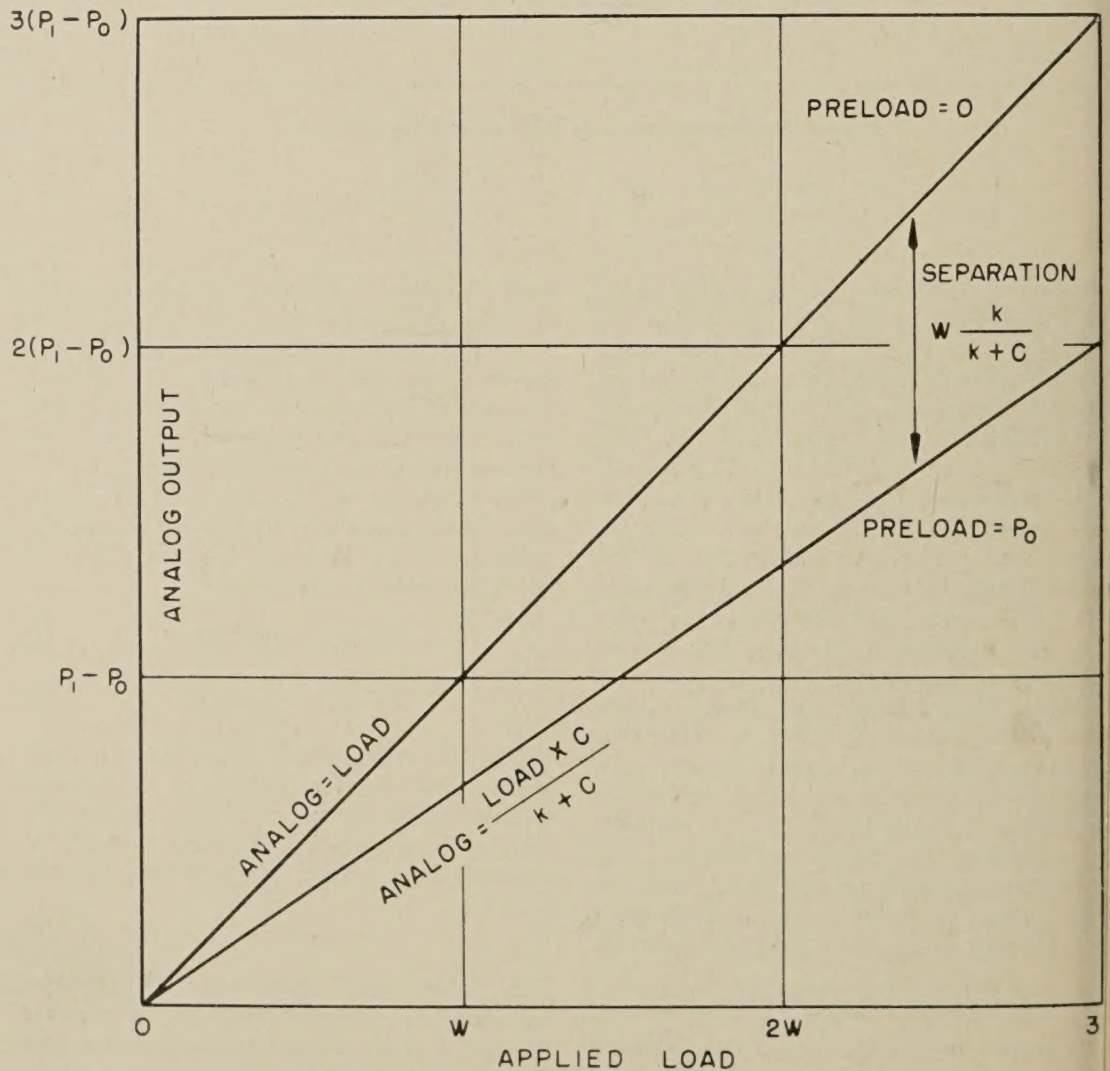
Figure 9.—Theoretical analog output as a function of applied load—preload constant
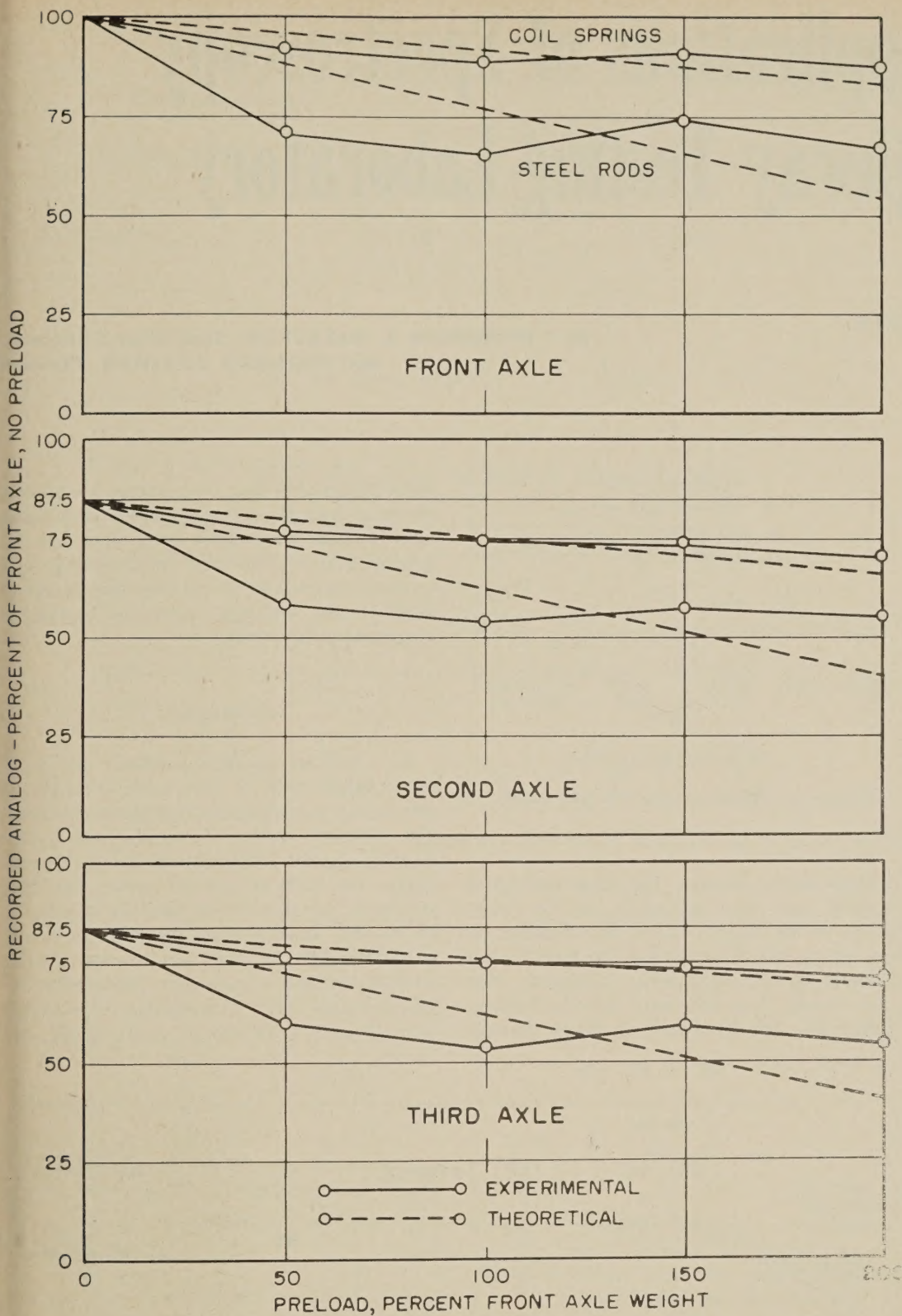
Figure 10.—*Experimental results that show reduction of sensitivity caused by preload.*

to 200 percent of the front-axle weight. Typical results for each of the 3 axles obtained from these tests are shown by figure 10.

Lines representing the theoretical sensitivity curves of the system have been included in figure 10 for comparison with the results of the experimental tests. Although the experimental curves do not coincide with the theoretical predictions, they have the same general trend in slope. Part of the difference in the curves has been attributed to some bending of the platform between the load-cell supports and the point at which the preload was applied to the platform. Other factors, such as changes in the value of k of the preload devices and inaccurate measurement of the preload being used, also may have accounted for some of the difference between the curves. The curves for preloading with springs and those for preloading with steel rods have different slopes; this difference shows the effect of the different values of k.

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Potential Applications of Spectroscopy in the Highway Testing Laboratory

BY THE
MATERIALS RESEARCH DIVISION
BUREAU OF PUBLIC ROADS

By [1] **WOODROW J. HALSTEAD**, Supervisory Chemist, and **BERNARD CHAIKEN**, Chemist

Highway testing laboratories are confronted with an increasing volume and variety of construction materials to be tested for compliance with chemical or mineralogical requirements. In addition, many new and complex materials used in construction, such as plastics, synthetic polymers, surface active agents, coatings, etc. are too complex to be effectively analyzed by ordinary chemical means. The potential advantages of using spectroscopy methods to provide more rapid and accurate analyses of materials than is otherwise possible by standard chemical procedures are discussed in this article. The suitability of spectroscopic techniques to determine the nature of complex materials, which cannot be practicably analyzed by chemical methods, is also discussed. The article includes general estimates of cost and time factors involved for several of the more useful techniques.

WAVELENGTH UNITS

A. = ANGSTROM UNIT = 10^{-8} cm.

mµ = MILLIMICRON = 10^{-7} cm.

µ = MICRON = 10^{-4} cm.

Figure 1.—*Electromagnetic spectrum.*

70 elements in a metal. The alkali content of cements and other materials can be determined in minutes by flame spectroscopy as opposed to the 3 or 4 days required for an analysis by older classical methods. Not quite ready, but definitely on the horizon within the next few years, are X-ray fluorescence techniques that will permit a complete chemical analysis of cement and similar materials in about 30 minutes, sometimes less. A general evaluation of new spectroscopic tools to determine if and where they can be put to work in the highway testing laboratory is presented in this article.

Summary

It is difficult to make a definite statement as to what type of instruments would be economical for all highway testing laboratories. The type and number of samples to be tested; whether special investigations are to be conducted as well as control tests; the time factors involved, all enter into the decision as to whether spectroscopic instruments should be purchased. In most laboratories, a flame photometer and a manually operated ultraviolet-visible light absorption spectrophotometer, at a total cost of about $3,000, can

Introduction

THE EVER-INCREASING numbers and types of materials submitted to the highway laboratory for tests have created serious problems for the testing engineer and not the least of these is the need for rapid methods of chemical analysis. Everyone is desperately longing for the ultimate gadget that will permit them to insert a sample in one end, push a button, wait 30 seconds, and have a complete report come out the other end.

This ultimate is, of course, a pipe-dream that most likely will never be completely realized. However, in some areas of analyses, this dream is closer to reality than might be suspected. The rapid development of arc spectroscopy in the last 10 to 15 years has provided the means of determining, within minutes, the absence or presence of as many as

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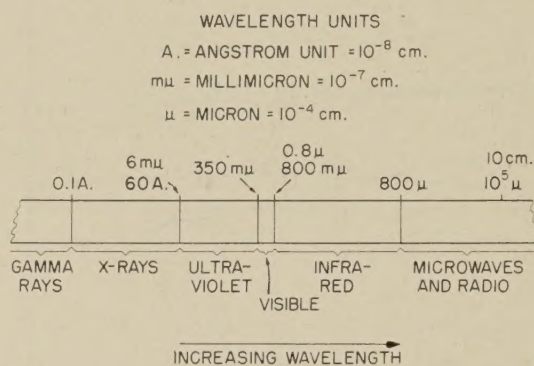[1] This article is based on a talk presented by Mr. Halstead at the 37th annual open meeting of the New Jersey, New York, and New England States Testing Engineers Association, Boston, Mass., Nov. 1961.

Figure 2.—*Schematic diagram of an absorption spectrophotometer.*
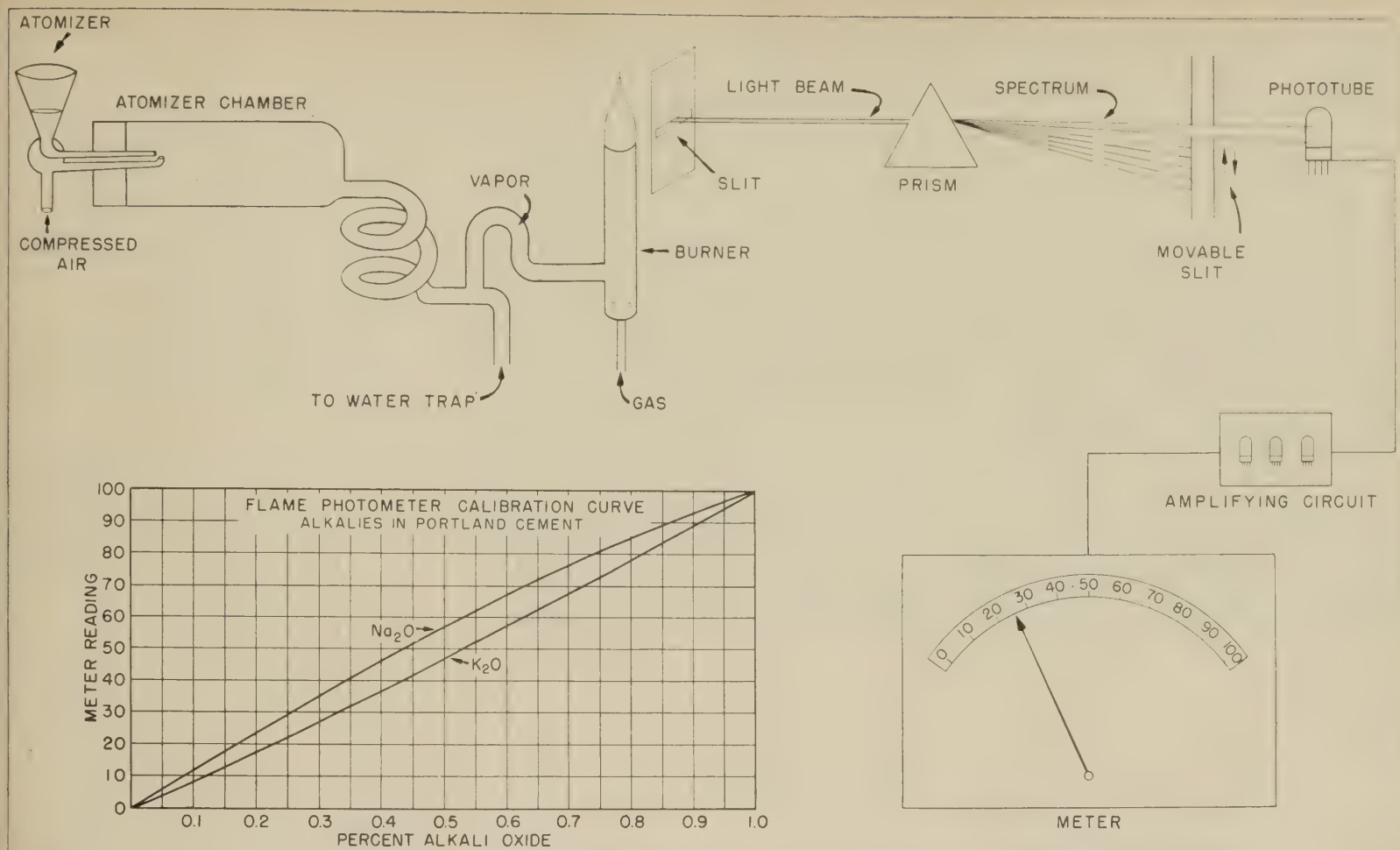
Figure 3.—*Schematic diagram of a flame photometer.*
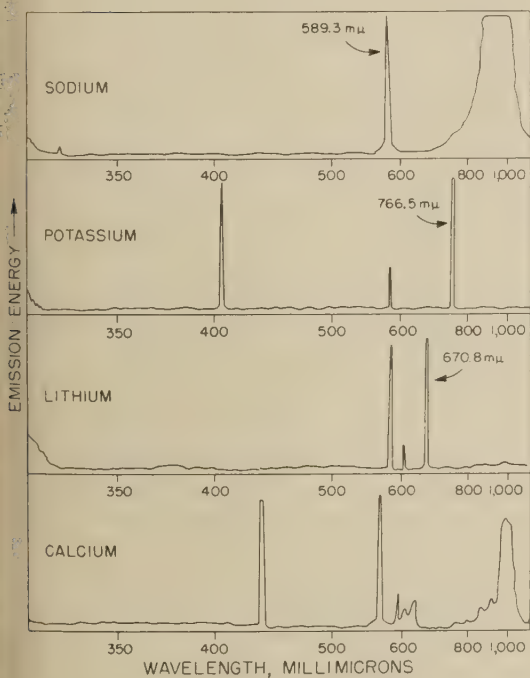
Figure 4.—*Flame spectra of elements.*
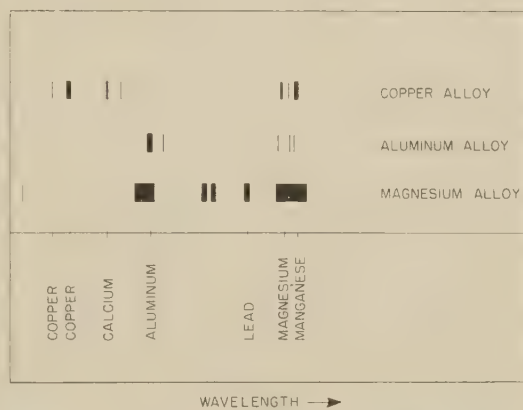
Figure 5.—*Type of spectra obtained with an arc emission spectograph.*

Figure 6.—*Ultraviolet absorption curve of phthalic acid. (Prepared from Bureau of Standards Sample 84e).*

easily be justified for: (1) routine testing of cements, rocksalt, and other materials for alkalies, (2) for work on concrete admixtures, (3) for identification of phosphorus in fertilizer, titanium in paint pigments, and alloying constituents in metals for which spectrophotometer methods are available.

An infrared spectrophotometer can be justified if the laboratory is regularly concerned with controlling the uniformity of proprietory concrete admixtures, rubber or synthetic water-stops, traffic paint vehicles, epoxy resins, silicones, herbicides, and similar complex organic materials. An instrument costing about $5,000 is suitable for accomplishing these purposes.

Arc and spark spectrographs can be justified only if very large volumes of metals must be analyzed. Considerable specialized accessory equipment is needed for this type of installation. The laboratory must be air conditioned, the humidity must be controlled, and a photographic dark room and metal working tools, such as lathes, belt polishers, etc., must be

provided. A minimum cost for adequate facilities would probably be about $40,000.

X-ray diffraction is very useful for identifying soils and solving problems related to the base or foundation of the highway, but it has limited application to specification control work. Nuclear magnetic resonance, at pres-
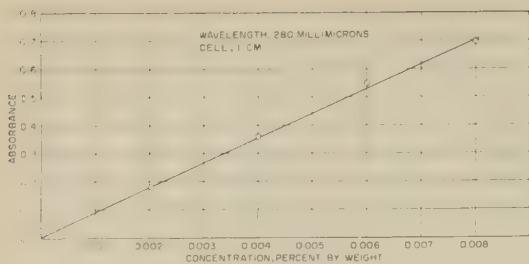
Figure 7.—Relation between concentration and ultraviolet absorbance of a lignosulfonate retarder.

ent, is essentially a research tool and its potential applications have not been considered in this discussion.

For the future, perhaps in 5 or 10 years, X-ray fluorescence may be developed to provide rapid and accurate analyses of major as well as minor constituents of many materials such as cements, alloys, and steels At the present time, however, X-ray fluorescence also should be considered a research tool. The present cost of this equipment is from $25,000 to $40,000.

Spectroscopy is a rapidly developing science and entirely new techniques are constantly being developed. For example, a relatively new instrument called "atomic absorption spectroscopy" has recently been introduced and it may make flame photometers obsolete. However, its potentialities for highway materials have not yet been evaluated.

Table 1 provides a guide to those interested in the present applicability of spectroscopic tools to the control of standard highway materials. The table shows only those instruments that have immediate applicability to the materials listed. The data presented should be considered as approximations only, and types of materials or analyses given are not necessarily complete.

Principles of Spectroscopy

The principle upon which all spectroscopic methods are based is the utilization and measurement of radiant energy in the electromagnetic spectrum. Figure 1 is a schematic diagram of this spectrum. All of the types of radiation illustrated—gamma, X-rays, ultraviolet, and visible light; infrared energy; and radio waves—are qualitatively identical in that they are light energy waves moving in accordance with the same basic law, which is,

Wavelength × Frequency = Speed of Light.

This means that frequency varies inversely with wavelength; that is, the shorter wavelengths of energy, such as X-rays and gamma rays, have greater frequencies. Frequency is also equated to photon energy—the greater the frequency, the greater the photon energy. Electromagnetic energy is utilized in two ways for practical analytical purposes: (1) it is absorbed by the test sample, hence the term *absorption* spectroscopy, and (2) it is emitted by the test sample, hence the term *emission* spectroscopy.

Figure 8.—Ultraviolet spectra of concrete admixtures.

Figure 9.—*Absorbance vs. concentration of phthalic acid solutions.*

Figure 10.—*An infrared spectrophotometer.*

Absorption spectroscopy

In absorption spectroscopy, visible light or some other form of radiant energy is allowed to pass through a sample, and the amount of light or energy absorbed at different wavelengths is recorded. A schematic diagram of the basic principles involved is shown in figure 2. As illustrated, the beam of light from the source is dispersed or spread out into its different wavelengths by either a prism or grating. Such radiation, either before or after dispersion, is permitted to pass through a sample and the amounts of energy absorbed by the sample at the different wavelengths are measured. The total energy absorbed for all wavelengths is recorded as a continuous spectrum, but that absorbed at an individual wavelength can be indicated as a meter reading, also shown in figure 2.

Instruments such as ultraviolet, visible light, and infrared spectrophotometers belong to the general class used for absorption spectroscopy. In a less rigorous sense, nuclear magnetic resonance, X-ray diffraction, and X-ray fluorescence equipment are also absorption spectrometers.
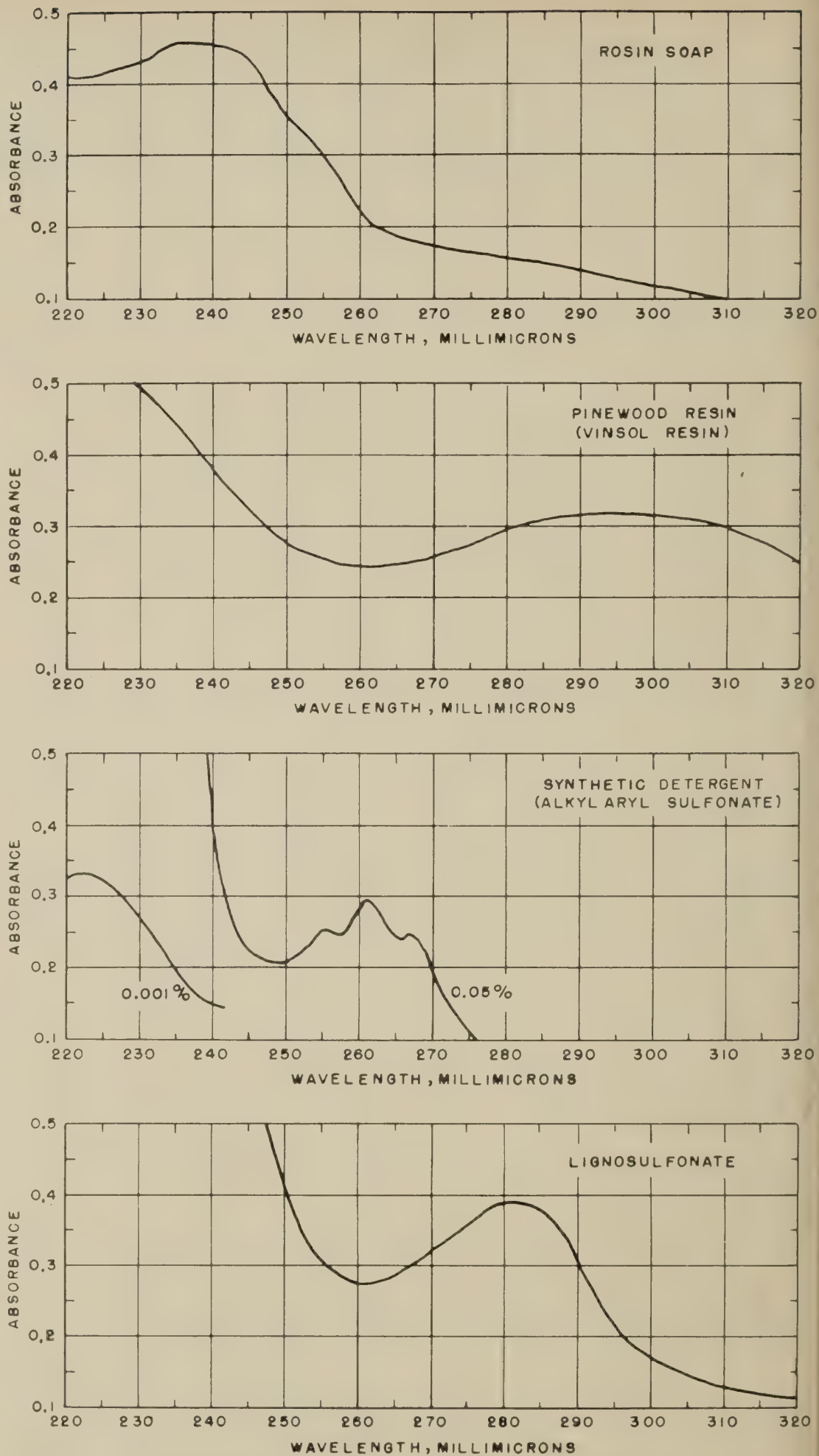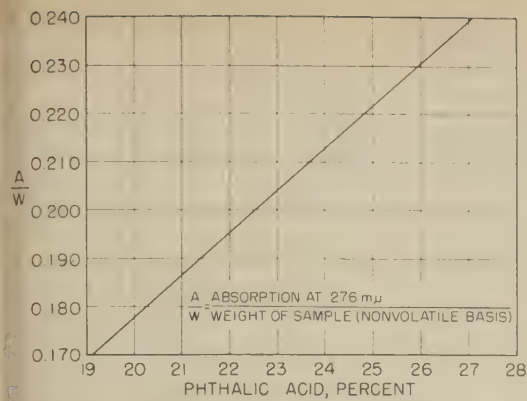
Emission spectroscopy

In emission spectroscopy, analysis of the material is based on the fact that many chemical elements, when sufficiently heated in a flame or electric arc, emit radiation or give off light having specific characteristics. When the emitted radiation from a particular sample is resolved or spread out by the dispersing medium of the instrument—either a prism or grating—an array of sharp, distinct, and separate lines is obtained. The positions of the different lines—their wavelengths—are related to the kinds of atoms present, and the intensities of the lines are proportional to their concentration. The flame photometer, typical of instruments used in the field of emission spectroscopy, is shown schematically in figure 3. The following list summarizes the more important techniques used for absorption and emission spectroscopy.

Absorption spectroscopy.—X-ray diffraction, X-ray fluorescence, ultraviolet, visible light, infrared, and nuclear magnetic resonance.

Emission spectroscopy.—Flame, and arc and spark.

Some of these techniques have little or no potential use in a highway testing laboratory but others are already being used, and still other techniques have considerable potential applications if the instrumentation can be further perfected. The general principles of several types of instruments that appear to have significant potential application to the analysis of highway materials are discussed in detail in the following portion of this article.
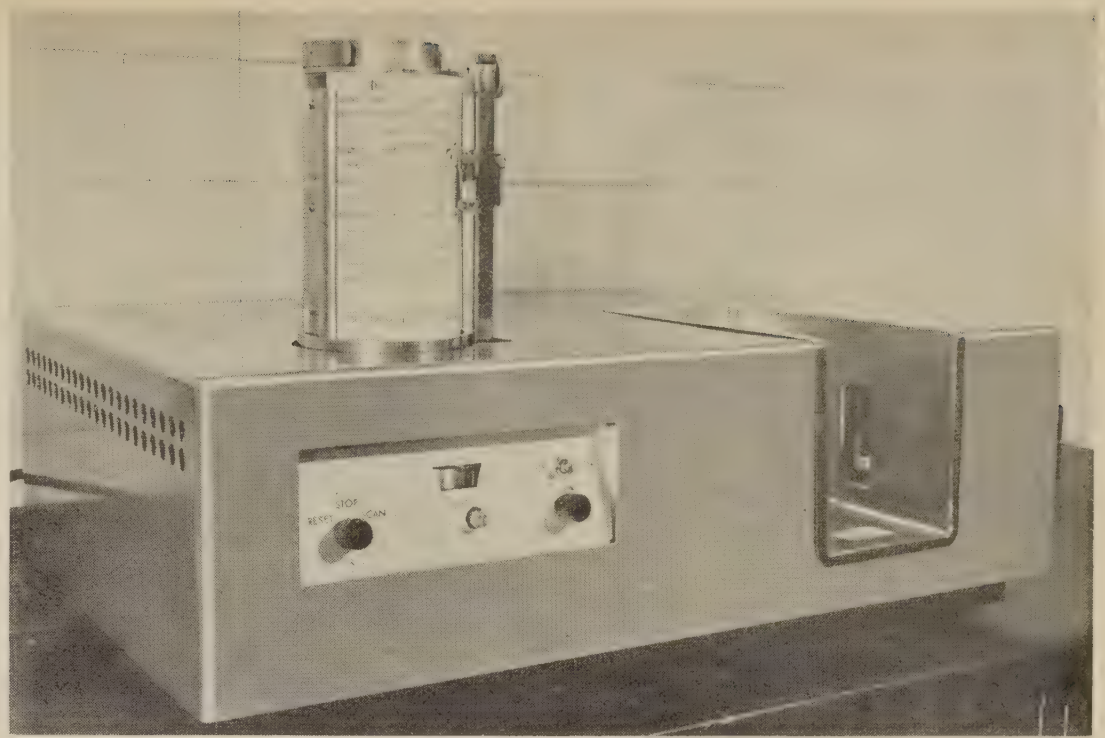
Flame Photometry

The flame photometer is perhaps the most familiar spectroscopic instrument to the highway engineer. It has been employed with excellent success during the past 15 years for the determination of alkalies, particularly sodium and potassium oxides, in cements and other substances. The principle involved in flame photometry requires that an element to be determined must be suitably excited by a flame so that it will emit characteristic radiations. The sample is dissolved in a suitable solvent if it is not already liquid, it is then atomized into a suitable gas flame for excitation, and a measurement is made of the resultant intensity of emitted radiation. The types of spectra that can be obtained with a special recording flame spectrophotometer are illustrated in figure 4. As shown, the response for specific elements is usually very sharp. However, commercial instruments are generally designed for quantitative work by meter readings, thus a wavelength is selected for each element at which the response for the desired element is strongest or at which interference from other substances would be at a minimum. The final result is a meter reading indicative of the intensity of emitted radiation, and it therefore is a measure of the concentration of the element sought.

Applications and instrumentation

Flame photometry is applicable only to inorganic constituents, either in solid or liquid samples. It is particularly applicable to the alkali metals—sodium, lithium, and potassium. Each of these elements emits characteristic radiation at a relatively low temperature such as that produced by an ordinary air-propane flame. For sufficient excitation of other elements, higher flame temperatures are required. In addition to being useful for alkali determinations in cement, flame photometers can be used to determine easily the amount of sodium in rocksalt ice-removal agents, and the potash content in fertilizers used for roadside seeding. The instrument has been used in exploratory work in connection with stripping tests of asphaltic materials; lithium salt was utilized as a tracer to quantitatively determine the degree of stripping.

Motor Vehicle Size and Weight Limits

A comparison of State legal limits of motor vehicle sizes and weights with standards recommended by the American Association of State Highway Officials is given in the table on pages 190–191. The statutory limits reported in this tabulation, prepared by the Bureau of Public Roads as of December 31, 1962, have been reviewed for accuracy by the appropriate State officials.

Statutory limits are shown for width, height, and length of vehicles; number of towed units; maximum axle loads for single and tandem axles; and maximum gross weights for single-unit truck, truck-tractor semitrailer combinations, and other combinations.

Line	State	Width inches [1]	Height ft.-in	Single unit — Truck	Single unit — Bus	Truck tractor semi-trailer	Other combination	Semi-trailer	Full trailer	Semi-trailer and full trailer	Single Statutory limit	Single Including statutory enforcement tolerance	Tandem Statutory limit	Tandem Including statutory enforcement tolerance	[cut off]
1	Alabama	96	13-6	35	40	50	NP	1	NP	NP	18,000	19,800	36,000	39,600	Tal...
2	Alaska	96	12-6	35	[19]40	60	60	1	1	2	18,000		32,000		Tal...
3	Arizona	96	13-6	40	40	65	65	1	1	2	18,000		32,000		Ta...
4	Arkansas	96	13-6	35	40	50	50	1	1	NP	18,000	[7]18,500	32,000	32,500	Spe...
5	California	96	13-6	35	[9]35	60	65	NR	NR	NR	18,000		32,000		Tal...
6	Colorado	[11]96	[12]13-6	35	40	60	[10]60	1	2	2	18,000		36,000		Fo...
7	Connecticut	102	12-6	50	50	50	NP	1	NP	NP	22,400	22,848	36,000	36,720	Spe...
8	Delaware	96	13-6	40	42	55	60	1	1	NP	20,000		36,000		Ta...
9	District of Columbia	96	12-6	40	40	50	50	1	1	NP	[46]22,000		38,000		Ta...
10	Florida	96	13-6	[14]35	40	55	55	1	1	NP	20,000	22,000	40,000	44,000	Ta...
11	Georgia	96	13-6	[15,]39	[15,]45	50	50	1	1	NP	18,000	20,340	36,000	40,680	Sp...
12	Hawaii	108	13-0	40	40	55	65	1	1	2	24,000		32,000		Fo...
13	Idaho	[11]96	14-0	35	[19]40	60	65	1	1	2	[20]18,000		[20]32,000		Ta...
14	Illinois	96	13-6	42	42	[25]55	60	1	1	2	[21]18,000		32,000		Sp...
15	Indiana	[11]96	13-6	36	40	50	[25]50	1	1	2	[23]18,000	[23]19,000	[23]32,000	[23]33,000	Sp...
16	Iowa	96	13-6	35	[19]40	50	50	1	[24]1	3	18,000	18,540	32,000	32,960	Ta...
17	Kansas	96	13-6	35	[19]40	50	50	1	1	NP	18,000		32,000		Ta...
18	Kentucky	96	[12]13-6	[26]35	[26]35	[27]50	[27]50	1	NP	NP	18,000	[28]18,900	32,000	[28]33,600	Sp...
19	Louisiana	96	13-6	35	[19]40	55	60	1	1	NP	18,000		32,000		Axl...
20	Maine	96	[30]12-6	55	55	55	55	1	1	NP	[30]22,000		[30]32,000		Ta...
21	Maryland	[18]96	[6]12-6	55	55	55	[40]55	NR	NR	NR	22,400		[31]40,000		Fo...
22	Massachusetts	96	NR	35	[19]40	50	NP	1	NP	NP	22,400		36,000		Ta...
23	Michigan	96	13-6	35	40	55	55	1	1	2	[33]18,000		[34]32,000		Ax...
24	Minnesota	96	13-6	40	40	50	50	1	1	NP	18,000		32,000		Te...
25	Mississippi	96	13-6	35	40	55	55	1	1	NP	18,000		28,650	[35]32,000	Te...
26	Missouri	96	12-6	35	40	50	50	1	1	2	18,000		32,000		Te...
27	Montana	[11]96	13-6	35	40	60	60	1	1	[37]2	18,000		32,000		Te...
28	Nebraska	96	13-6	40	40	60	60	1	1	[5]2	18,000	18,900	32,000	33,600	Te...
29	Nevada	96	NR	NR	NR	NR	NR	NR	NR	NR	18,000	18,900	32,000	33,600	Te...
30	New Hampshire	96	13-6	35	[35]40	50	50	NR	NR	NR	22,400		36,000		Tres...
31	New Jersey	[44]96	[44]13-6	35	[39]35	50	[40]50	1	1	NP	22,400	23,520	32,000	33,600	Sp...
32	New Mexico	[41]96	13-6	40	40	65	65	1	1	2	21,600		34,320		Te...
33	New York	96	[6]13-0	35	[42]35	50	50	1	1	NP	22,400		36,000		Fr...
34	North Carolina	96	[6]12-6	35	[19]40	[43]50	[43]55	1	1	NP	18,000	19,000	36,000	38,000	Sp...
35	North Dakota	[44]96	[44]13-6	[14]35	[19]40	60	60	1	1	2	18,000		32,000		Fr...
36	Ohio	96	13-6	35	[19]40	50	60	1	NR	NR	19,000		31,500		Fr...
37	Oklahoma	96	13-6	35	45	[45]60	[45]60	1	1	NP	18,000		32,000		Te...
38	Oregon	96	[12]13-6	35	[35]40	[25,35]55	[35]65	1	1	[35]2	[47]18,000		[47]32,000		Tie...
39	Pennsylvania	95	[6]12-6	35	40	[56]50	[40]50	1	1	NP	22,400	23,072	36,000	37,080	Sp...
40	Puerto Rico	96	12-6	35	40	50	50	1	1	NP	NS		NS		Sp...
41	Rhode Island	102	12-6	40	40	50	50	1	1	NP	22,400		NS		Sp...
42	South Carolina	96	13-6	[14]35	[19]40	55	[59]60	1	1	NP	20,000		32,000		Te...
43	South Dakota	96	13-6	35	40	60	60	1	1	2	18,000		32,000		Te...
44	Tennessee	96	[6]12-6	35	40	50	50	1	[53]1	NP	18,000		32,000		Te...
45	Texas	96	13-6	35	40	50	50	1	1	NP	18,000	18,900	32,000	33,600	Te...
46	Utah	96	14-0	45	45	60	60	NR	NR	NR	18,000		[64]33,000		Tie...
47	Vermont	96	12-6	50	50	50	50	1	1	NP	NS		NS		Sp...
48	Virginia	96	13-6	35	40	50	50	1	1	NP	18,000		[57]32,000		Te...
49	Washington	96	13-6	35	[19]40	60	[58]65	1	1	[58]2	18,000		32,000		Te...
50	West Virginia	96	[6]12-6	35	[19]40	50	50	1	1	NP	18,000	18,900	32,000	33,600	Te...
51	Wisconsin	96	13-6	35	40	50	[67]50	1	1	NP	18,000	[60]19,500	30,400	32,000	Te...
52	Wyoming	96	13-6	40	40	65	65	1	1	2	18,000		32,000	[62]36,000	Te...
	AASHO Policy	96	12-6	35	[19]40	50	60	1	1	NP	18,000		32,000		Tie...
	Number of States — Higher	3	45	18	33	26	9	5	6	24	31		30		Fnul...
	Number of States — Same	49	7	34	14	26	13	47	42	28	21		21		Tle...
	Number of States — Lower	0	0	0	5	0	30	0	0	4	0		1		Scr...

NP—Not permitted.   NR—Not restricted.   NS—Not specified.

[1] Various exceptions for farm and construction equipment; public utility vehicles; house trailers; urban, suburban, and school buses; haulage of agricultural and forest products; at wheels of vehicles for safety accessories, on designated highways, and as administratively authorized.

[2] Various exceptions for utility vehicles and loads, house trailers and mobile homes.

[3] When not specified, limited to number possible in practical combinations within permitted length limits; various exceptions for farm tractors, mobile homes, etc.

[4] Legally specified or established by administrative regulation.

[5] Computed under the following conditions to permit comparison on a uniform basis between States with different types of regulation:
A. Front axle load of 8,000 pounds.
B. Maximum practical wheelbase within applicable length limits:
(1) Minimum front overhang of 3 feet.
(2) In the case of a 4-axle truck-tractor semitrailer, rear overhang computed as necessary to distribute the maximum possible uniform load on the maximum permitted length of semitrailer to the single drive-axle of the tractor and to the tandem axles of the semitrailer, within the permitted load limits of each.
(3) In the case of a combination having 5 or more axles, minimum possible combined front and rear overhang assumed to be 5 feet, with maximum practical load on maximum permitted length of semitrailer, subject to control of loading on axle groups and on total wheelbase as applicable.
C. Including statutory enforcement tolerances as applicable.

[6] Auto transports 13 feet 6 inches; Maryland also allows 13 feet 6 inches for vehicles loaded with hay or straw, or carrying flat glass.

[7] Does not apply to combinations of adjacent load-carrying single axles.

[8] 56,000 pounds on load-carrying axles, exclusive of steering-axle load.

[9] On specific routes in urban or suburban service under special permit from P.U.C. 40 feet, also 3-axle buses with turning radius less than 45 feet without restriction.

[10] Except 3-unit combinations may use up to 65 ft. combinations on certain highways designated by the Department of Highways

[11] Buses 102 inches on highways of surfaced width at least 20 feet or otherwise as administratively authorized.

[12] On class AA, or designated highways, 12 ft. 6 in. on other highways; log and lumber trucks limited to 12 ft. 6 in. on all highways in Oregon.

[13] Legal limit 60,000 pounds, axle spacing 27 feet or more.

[14] Three-axle vehicles 40 feet.

[15] Truck 39.55 feet; bus 45.20 feet.

[16] 63,280 pounds maximum, except on ids...

[17] 700 (L + 40) when L is 18' or less; [8](L...
tures with span of 20' or over.

[18] Vehicles loaded with tobacco hogsh...

[19] Less than three axles 35 feet.

[20] Special limits for vehicles hauling tier...
products including livestock; single axle 18,...
axles permitted 66,000 pounds maximum at 2...
at 43-foot axle spacing.

[21] On designated highways; 16,000 po...

[22] Without tandem axles 45,000 pounds

[23] On designated highways; single axl...
all excesses of weight under one or more limi...
front or steering axle.

[24] Towing agent must be registered for...
registered as "Farm trailer."

[25] 60 ft. in special cases: Illinois, au...
tractor semitrailers on designated major rout...

[26] On designated highways; trucks 26...

[27] Class AA highways; 45 feet on oth...

[28] Class AA highways only.

[29] Maximum gross weight on Class A h...

[30] Including load 14 feet; various exce...

[31] Tandem axles spaced less than 48...

[32] Subject to axle and tabular limits.

[33] Single axle spaced less than 9 feet...

[34] On designated highways only and li...

[35] On designated highways only.

[36] Administrative regulation—32,000 p...
and 5 is 28 ft. or more.

[37] Semitrailer and semitrailer conver...

[38] Dual-drive axles; otherwise 40,000...

[39] Or as prescribed by P.U.C.

[40] Exception for poles, pilings, struct...

mit		Specified maximum gross weight—pounds[4]						Practical maximum gross weight—pounds[5]						
Applicable to:		Truck		Truck-tractor semitrailer			Other combination	Truck		Truck-tractor semitrailer			Other combination	Line
y up s	Total wheel base only	2-axle	3-axle	3-axle	4-axle	5-axle		2-axle	3-axle	3-axle	4-axle	5-axle		
X	Over 18'	36,000	50,000	50,000	72,000	76,800	76,800	27,800	47,600	47,600	60,010	64,650	NP	1
r 18'	Over 18'							26,000	40,000	44,000	58,000	72,000	76,800	2
r 18'								26,000	40,000	44,000	58,000	72,000	76,800	3
r 18'	Over 18'							26,500	40,500	45,000	59,000	65,000	65,000	4
								26,000	40,000	44,000	58,000	72,000	76,000	5
X		30,000	46,000					26,000	44,000	44,000	62,000	76,000	76,000	6
		32,000	50,000	50,000	60,000	60,000	NP	30,848	44,720	51,000	61,200	61,200	NP	7
X		30,000	46,000	48,000				28,000	44,000	48,000	64,000	73,280	73,280	8
X					70,000	70,000	70,000	30,000	46,000	52,000	[54]68,000	[54]70,000	[54]70,000	9
X								30,000	52,000	52,000	65,200	73,095	73,095	10
							63,280	28,340	48,680	48,680	63,280	63,280	63,280	11
X								32,000	38,800	56,000	64,000	72,000	80,000	12
X								26,000	40,000	44,000	58,000	73,280	76,800	13
		36,000	[22]41,000	45,000	59,000	72,000	72,000	26,000	40,000	44,000	58,000	72,000	72,000	14
							72,000	27,000	41,000	45,000	59,000	[23]73,000	[23]73,000	15
X								26,540	40,960	45,080	59,500	73,280	73,280	16
X								26,000	40,000	44,000	55,470	73,280	73,280	17
		27,000	42,000	42,000	59,640	73,280	NP	27,000	42,000	42,000	59,640	73,280	73,280	18
				51,800	60,050	70,550		26,000	40,000	44,000	58,000	72,000	76,000	19
X		32,000	[30]51,800	65,000	65,000	65,000	70,550	30,000	40,000	51,800	62,040	70,550	70,550	20
X							65,000	30,400	48,000	52,800	65,000	65,000	65,000	21
		[32]46,000	[32]60,000	[32]60,000	[32]73,000	[32]73,000	NP	30,400	44,000	52,800	66,400	73,000	NP	22
X						[36]73,280		26,000	[35]40,000	44,000	[35]58,000	[35]66,000	[35]102,000	23
X								26,000	40,000	44,000	58,000	[36]72,000	72,500	24
								26,000	[35]40,000	44,000	59,000	[35]64,650	[35]64,650	25
X	Under 18'							26,000	40,000	44,000	55,470	64,650	64,650	26
X		36,000	54,000	54,000	71,146	71,146	71,146	26,000	40,000	44,000	58,000	72,000	76,000	27
r 18'	Under 18'							26,780	41,200	45,320	59,740	73,280	73,280	28
								26,900	41,600	45,800	60,500	75,200	76,800	29
X		33,400	[38]47,500	52,800	66,400			30,400	44,000	52,800	66,400	66,400	66,400	30
		30,000	40,000	60,000	60,000	60,000	60,000	31,500	41,600	55,040	63,000	63,000	63,000	31
r 18'	Over 18'					65,000	65,000	29,600	42,320	51,200	63,920	76,640	86,400	32
X								30,400	44,000	52,800	65,000	65,000	65,000	33
r 18'	Over 18'	31,500	46,200	46,200	65,100	65,100	65,100	27,000	46,000	46,000	65,100	65,100	65,100	34
	X							26,000	40,000	44,000	60,000	[44]64,000	[44]64,000	35
								27,000	39,500	46,000	58,500	71,000	78,000	36
X								26,000	40,000	44,000	58,000	72,000	73,280	37
r 18	Over 18'					[48]76,000	[48]76,000	26,000	40,000	44,000	58,000	72,000	[48]76,000	38
		33,000	47,000	50,000	60,000	60,000	62,000	31,072	45,080	51,500	61,800	61,800	63,860	39
														40
		[50]36,000	[51]44,000	[52]50,000	[13]60,000	60,000	88,000	30,400	44,000	50,000	60,000	60,000	88,000	41
X								28,000	40,000	48,000	60,000	66,839	71,115	42
X								26,000	40,000	44,000	58,000	72,000	73,280	43
	X							26,000	40,000	44,000	58,000	61,580	43,500	44
X								26,900	41,600	45,800	60,500	75,200	75,600	45
X		[55a]32,000	[55b]55,000	[55c]52,800	[55d]66,400	[55d]66,400	[55d]66,400	36,000	51,000	54,000	69,000	79,900	79,900	46
X						70,000	70,000	[55a]32,000	[55b]55,000	[55c]52,800	[55d]66,400	[55d]66,400	[55d]66,400	47
						68,000	70,000	26,000	40,000	44,000	60,000	70,000	70,000	48
18'	Over 18'	28,000	36,000	46,000	60,000	68,000	72,000	26,000	36,000	44,000	60,000	68,000	72,000	49
X					[66]70,000	[66]70,000	[66]70,000	26,900	41,600	45,800	57,844	63,840	63,840	50
X								27,500	40,000	47,000	59,500	73,000	73,000	51
X								26,000	44,000	44,000	62,000	73,950	73,950	52
X								26,000	40,000	44,000	55,470	61,490	71,900	
20	18							30 21 0	27 21 3	29 21 1	49 2 0	49 0 2	32 0 19	

ut ity 56,000 pounds maximum.

nn 18'; 900 (L + 40) on highways having no struc-

, o concentrates, aggregates, and agricultural
7, pounds, gross weight table: vehicle with 3 or 4
le 5 or more axles permitted 79,000 pounds maximum

oxl r ,000 pounds; tolerance of 1,000 pounds on total of
gro weight; depending upon the placing of 9000# on the
lire mbination of vehicles except farmer having trailer

r, t ks pulling house trailers only; Oregon, truck

on o highways.

on C s B highways 30,000 pounds.
ng f t products and construction materials.
we limitation of 36,000 pounds.

to 00 pounds.
n c pination; otherwise 26,000 pounds.

d ol dum axles provided the distance between axles 2
c n ly.

etc rmitted 70 feet.

[41] On designated highways 102 inches. Body restricted to 96", additional 6" for tires only.
[42] Trackless trolleys and buses 7 passengers or more, P.S.C. certificate 40 feet.
[43] Including front and rear bumpers.
[44] Vehicles in excess may be operated under special permit obtained in advance from the Department of Motor Vehicles; in North Dakota, from State Highway Truck Regulatory Department.
[45] Auto transports only, by special permit only, otherwise 50 feet.
[46] Any single axle exceeding 18,000 lbs. shall be equipped with 4 properly inflated tires.
[47] Logging vehicles permitted 7-foot wheelbase tolerance, 19,000-single axle, 34,000-pound tandem axle.
[48] Governs gross weight permitted on highways designated by resolution of State highway commission.
[49] Single unit truck with 4 axles permitted 60,000 pounds.
[50] Axles spaced less than 6 feet 32,000 pounds; 12 feet or more gross weight governed by axle limit.
[51] Single vehicle with 3 or more axles spaced less than 16 feet 40,000 pounds; less than 20 feet 44,000 pounds; 20 feet or more governed by axle limit.
[52] Tractor semitrailer with 3 or more axles spaced less than 22 feet 46,000 pounds; not less than 27 feet 50,000 pounds.
[53] Limited to 3,500 pounds.
[54] Several bridges posted at lower limits.
[55] On Interstate Routes: a. 30,000 lbs.; b. 40,000 lbs.; c. 50,000 lbs.; d. 60,000 lbs.
[56] Where truck-tractor was properly registered in Pennsylvania as of December 31, 1961, 55 feet.
[57] Vehicles registered before July 1, 1956, permitted limits in effect January 1, 1956, for life of vehicle.
[58] Three-unit combinations and full truck and full trailer combinations on designated highways.
[59] House trailers only, otherwise 55 feet.
[60] Axle load 21,000 pounds on 2-axle trucks hauling peeled or unpeeled forest products cut crosswise or transporting milk from farm to market but not over Interstate System.
[61] On Class A highways. All axles of a vehicle or combination—73,000 pounds maximum. Wheel, axle, axle group and gross vehicle weights on Class B highways are 60% of weights including tolerance authorized for Class A highways.
[62] Based on ruling of Attorney General.
[63] Weight limits to be established by administrative regulations.
[64] For axle spacing under 8 feet.
[65] Weights are established on axle spacing of the extreme of any group.
[66] Only on certain highways, or portions thereof, designated by State Roads Commissioner, and consistent with Congressional action.
[67] Mobile house and towing vehicle—50 feet except Noon to Midnight Sundays and other designated holidays.

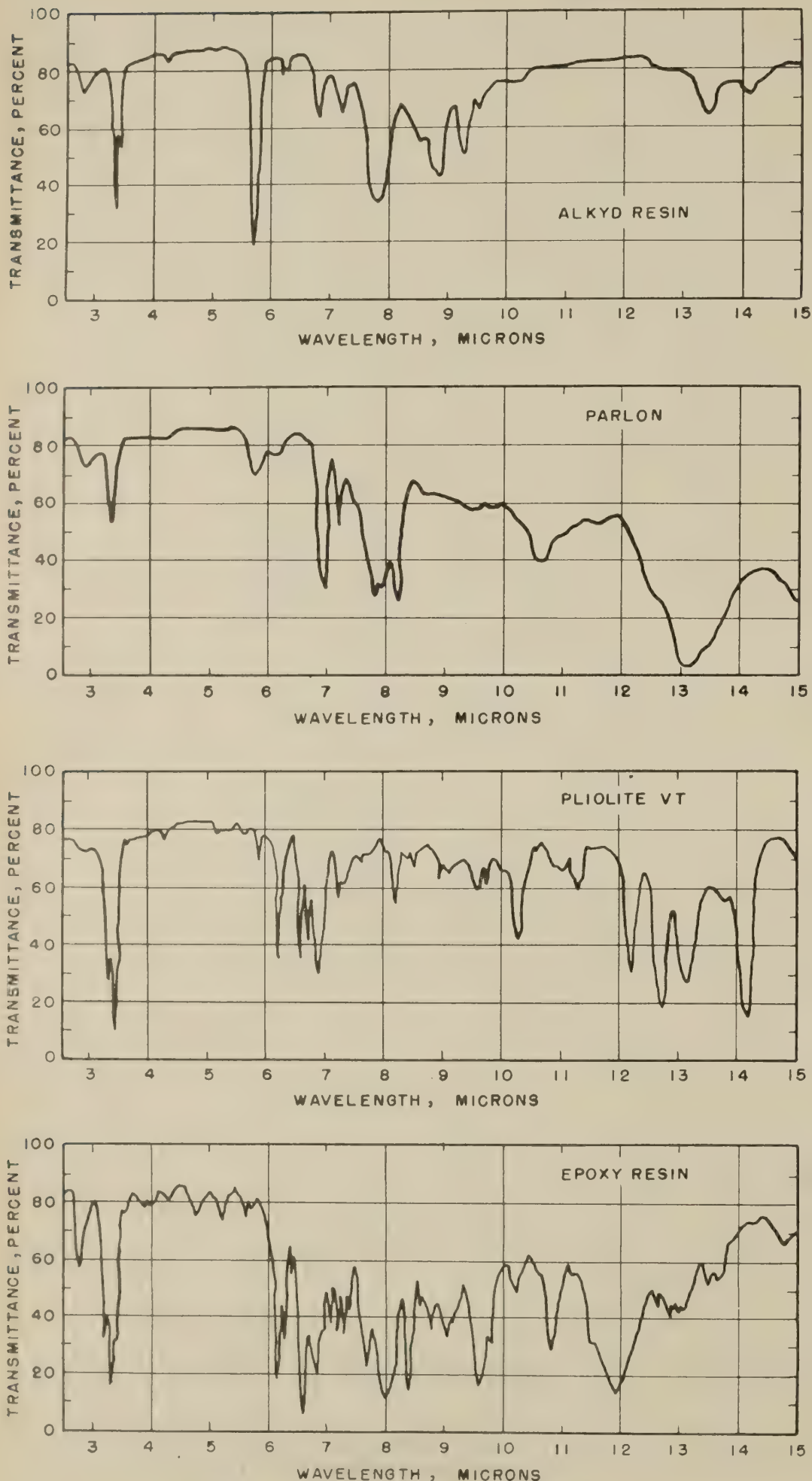# Potential Applications of Spectroscopy in the Highway Field

Figure 11.—*Infrared spectra of paint resins.*

In recent reports, flame photometric methods have been developed for the individual determinations of manganese, magnesia, and the alkalies in a single solution of cement (*1, 2, 3*).[2] However, these procedures have not been developed to an acceptable level for routine application.

Much testing time can be saved by use of the flame photometer. For example, the classical gravimetric method for determining the alkalies in portland cements requires 3 to 4 days. With flame photometry, 10 to 15 samples can easily be run in less than a day. This great saving in time for such analyses, coupled with the relatively moderate cost of the instrument, makes the purchase of such equipment worthwhile for analyzing even a relatively small number of samples, 20 to 30 a year.

Flame photometers are available either as a separate tool or as an attachment to manually operated ultraviolet-visible light absorption spectrophotometers. The cost of flame photometers ranges from $500 to $2,500 depending on the refinements of the circuit. The presently available filter-type instruments, which are generally lower priced, are not sufficiently accurate for the determination of the alkali content of cements. The present ASTM and AASHO methods for cement alkalies require a light-dispersing prism or grating and have been written around a specific instrument. However, revisions in these methods are now being made so that any commercial type of instrument may be used provided it produces results within a prescribed degree of accuracy for tests on standard cements of certified alkali content.

Arc and Spark Spectroscopy

The classic example of emission spectroscopy is the arc or spark spectrograph. In principle arc and spark spectroscopy is similar to flame photometry, except that the sample is vaporized and excited by an electric arc or spark rather than by a flame. Here again, only the inorganic elements present can be determined and identified. The arc or spark spectograph is one of the most highly sensitive tools available for analytical work. In its operation, a small sample is burned between electrodes in an electric arc or spark and the sample's spectrum is recorded on a photographic plate or other sensing device. An inspection of the resultant pattern of spectral lines serves to confirm the presence or absence of about 70 of the chemical elements. The positions of the lines are used to qualitatively identify the elements that are present, and the intensity of each line is used as a quantitative measure of the amount of each element present. A typical spectrum of the type obtained on a photographic plate is shown in figure 5.

Quantitative results from arc and spark
spectrographs are obtained by comparing the
densities of the lines of the test sample with
the intensities of lines from standard samples
of known composition. In order to obtain
suitable accuracy it is necessary to make a
careful standardization of the photographic
emulsion, match the unknown with a standard
of similar composition, and obtain accurate
measurements of the intensities. Under these
conditions, accuracy is in the range of 5 to 15
percent of the amount of the constituent
present, provided the amount of the con-
stituent does not exceed 10 percent of the
sample. Accurate quantitative determina-
tions cannot be made for major constituents
that make up more than 10 percent of the
sample.

Newer types of spectrographic instruments,
which have a photoelectric system for quan-
titative read out, have much greater accuracy
and precision for quantitative work (about
1 percent of the element present). However,
these instruments are very expensive and are
limited in scope when used for qualitative
applications. Such instruments are most
suitable for a large volume of repetitive deter-
minations of the same elements in the same
types of materials.

Application and instrumentation

Many materials of interest to the highway
engineer can be analyzed by an arc and spark
spectrograph. These include minor constitu-
ents in aluminum and other metallic alloys,
minor constituents in steel, alkali and alkali
salts, minerals, and even paint pigments.
However, certain constituents of metals such
as carbon, sulfur, and phosphorous cannot be
determined by this instrument. The cost of
arc and spark spectographic equipment is
high—$15,000 to $20,000. The additional
cost of required accessories increases the total
cost for establishing a complete spectrographic
laboratory to $40,000 or more. A highway
laboratory having a very large volume of
metal samples for chemical analysis may be
able to justify such equipment.

Ultraviolet and Visible Light Spectroscopy

The color of any object is the result of
absorption of certain wavelengths of white
light and reflection or transmission of others.
Thus, the absorption of specific wavelengths
of energy by particular substances is a familiar
phenomenon even though it may not have
been recognized. The technical explanation
of the phenomenon is rather involved. It
relates to the difference in the energy of the
electrons in the sample before and after the
absorption of critical radiation. This, in
turn, is related to specific characteristics of
molecules of substances. The type of curve
obtained when the ultraviolet spectrum is
recorded is shown in figure 6. For some
classes of compounds, the peaks in the curve
will always occur in approximately the same
region. Thus, qualitatively, the wavelength
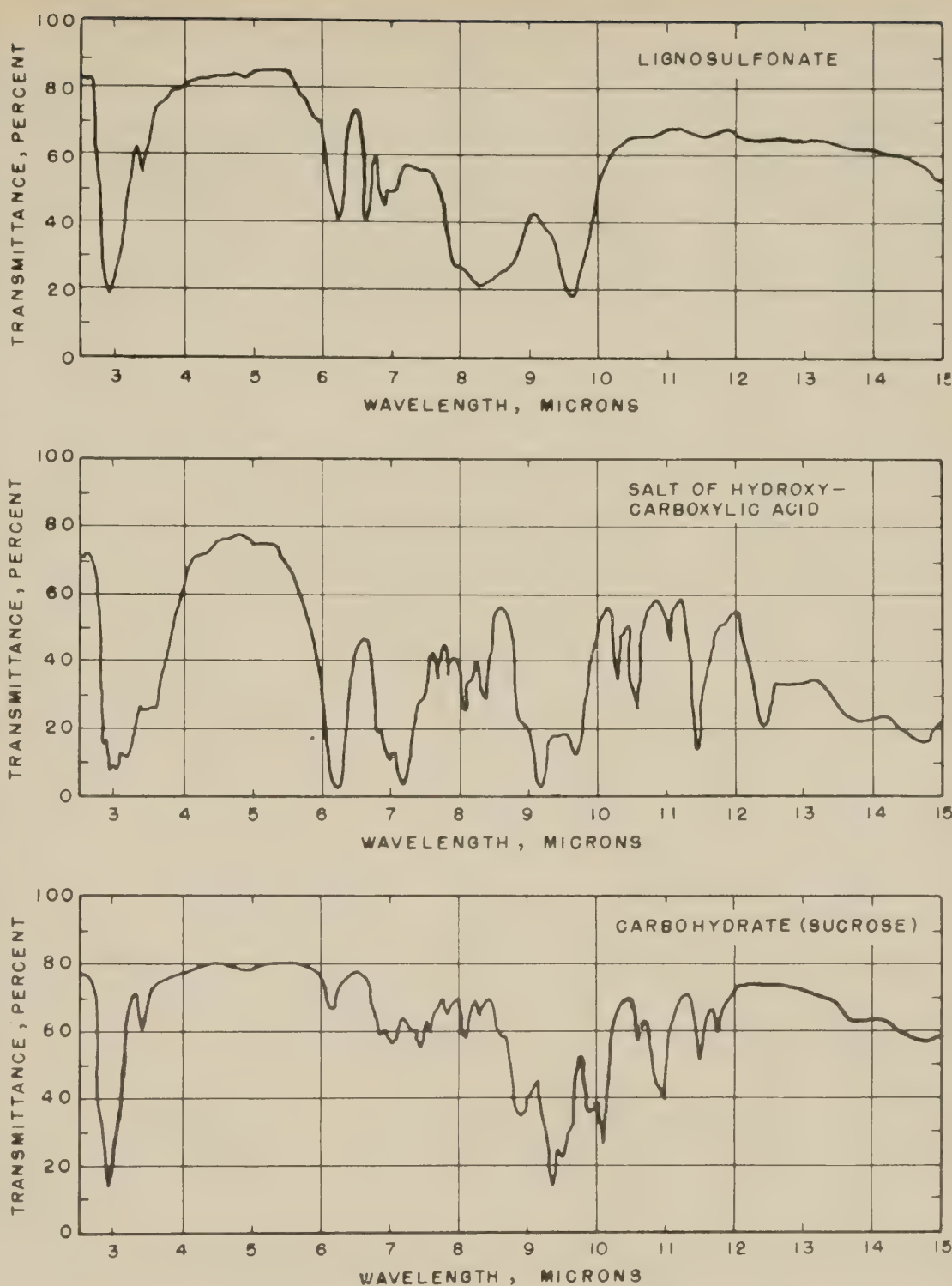location of the peak is of some value. How-

Figure 12.—*Infrared spectra of concrete retarding admixtures.*

ever, the greatest application of both ultra-
violet and visible light absorption measure-
ments for highway materials is in quantitative
analysis. The quantitative measurement is
the vertical displacement of the peak—the
absorbance of the sample.

It is known that the amount of light ab-
sorbed by dilute solutions of a substance is
directly related to the amount of dissolved
substance present. Thus, the absorption of a
test solution is obtained and its concentration
is determined from a calibration curve pre-
viously established for solutions containing
known amounts of the substance under test.
A typical calibration curve for a lignosulfonate
material is illustrated in figure 7. The same
principle is applied to both the ultraviolet and
visible light wavelength bands.

Compounds that absorb energy in the ultra-
violet region are generally organic in nature
and those that absorb energy in the visible
region are usually inorganic. The absorbed
light in the visible region is related to the color
characteristics of the sample.

Application of ultraviolet spectroscopy

At the Public Roads laboratory, ultraviolet
spectral analysis is used in conjunction with
infrared spectroscopy to control the chemical
uniformity of air-entraining and retarding
admixtures for concrete. Information on part
of this work has been published (4), typical
ultraviolet spectra of such admixtures for con-
crete are shown in figure 8. The height of
each peak—the absorbance—is directly related
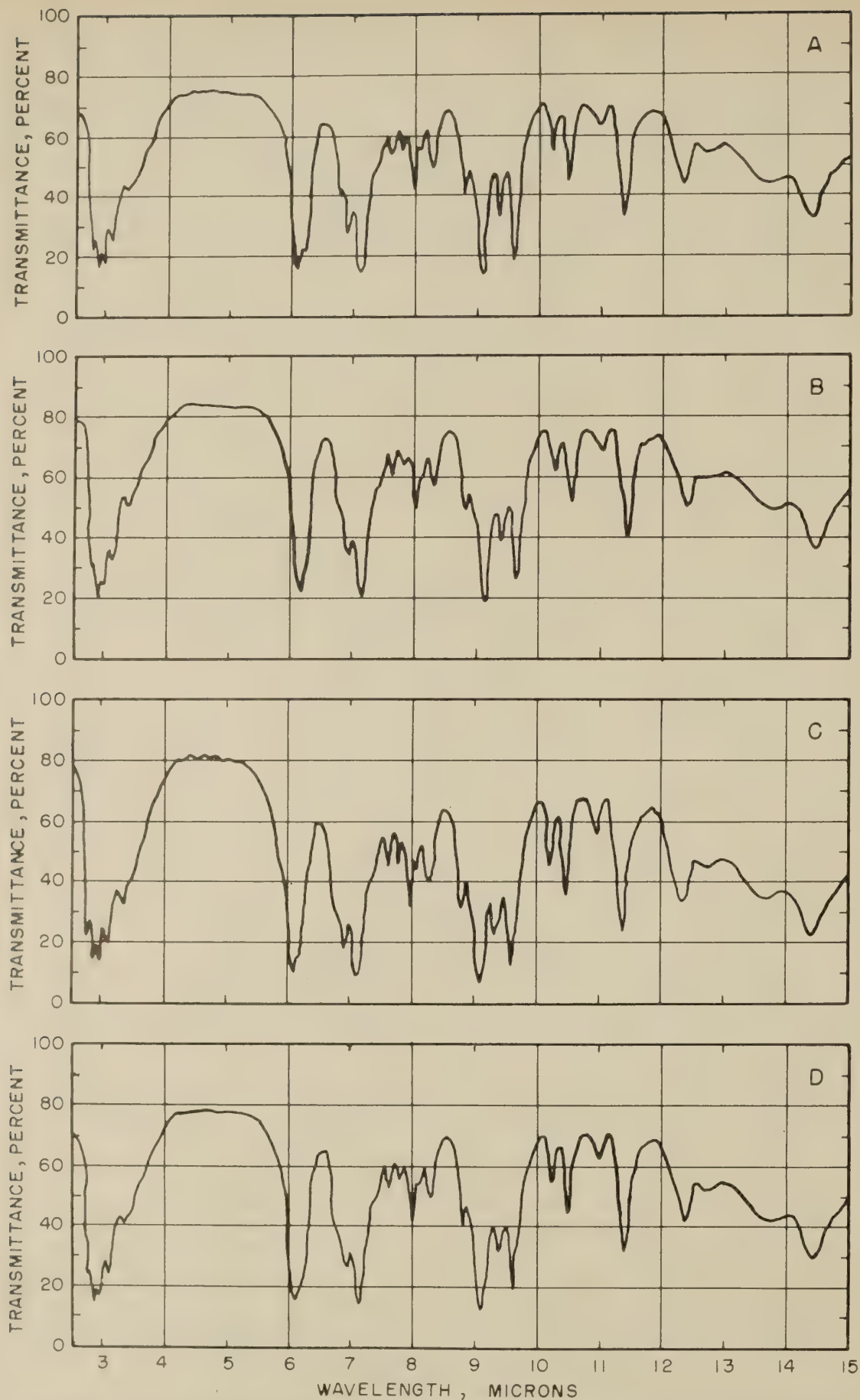to the concentration of the active ingredient.

Figure 13.—Infrared spectra of four different lots of the same trade name retarder (hydroxy-carboxylic type).

Other laboratories use an ASTM ultraviolet spectrophotometric method to determine the phthalic anhydride content of alkyd resin paints (5). The curve for phthalic acid, shown in figure 6, has a peak at a wavelength of 276 millimicrons, which is characteristic of this material. The absorbance measurement (vertical displacement) at 276 millimicrons is proportional to the concentration of the phthalic acid in the sample. This relationship is shown in figure 9.

Application of visible light absorption spectroscopy

In the visible region of the spectrum a manually operated instrument often is used to determine the presence of constituents such as phosphorus in fertilizers, titanium in paint pigments and portland cements, and soluble silica in the ASTM chemical test for potential alkali-aggregate reactivity of concrete aggregates. Such spectrophotometric methods provide much more rapid analyses than ordinary chemical procedures and are especially useful when the amount of the constituent to be determined is very small.

Instrumentation

Automatic recording ultraviolet and visible light spectrophotometers are very expensive—from $5,000 to $10,000. These instruments are useful mainly for research and special investigations on organic materials. Automatic recording instruments can scan the entire ultraviolet spectrum in a period of time as short as 1 or 2 minutes, whereas the use of manually operated instruments for this purpose may require 1 or 2 hours and considerable effort. For quantitative analyses, both in the visible and ultraviolet regions, a reading is usually taken at a specific wavelength; consequently, the manually operated instruments are entirely adequate for such applications and their cost is about $2,500, perhaps less.

Infrared Spectroscopy

Infrared spectroscopy is similar to ultraviolet spectroscopy in that it detects the presence of groups of atoms rather than the element itself, but it differs in that vibrating atoms or groups of atoms, rather than electrons, are responsible for the absorption of the incident energy. Such atomic groups vibrate with definite, sharply defined frequencies that are characteristic of the molecular combinations. These frequencies lie in the infrared or radiant heat region of the electromagnetic spectrum, which extends from the red end of the visible region (about 0.8 microns) to 35 microns and beyond. When a sample is placed in a beam of such radiation, it absorbs infrared energy at frequencies characteristic of

the molecule and transmits all other frequencies. The resultant pattern, known as an infrared absorption spectrum, is probably the most characteristic physical property of all compounds. No two compounds of different structure or different chemical nature will have identical infrared spectra. For this reason the infrared spectrum of a material is often referred to as a characteristic fingerprint.

Most functional groups (parts of chemical compounds) have a characteristic absorption at fixed frequencies. Thus, the infrared spectrum of a substance can also indicate the presence or absence in a compound of chemical groups such as carbonyl, hydroxyl, carboxylic acid, ether, vinyl, aromatic rings—just to mention a very few. Consequently, both the original chemical nature and structure, as well as the chemical changes occurring during aging or exposure of materials, can be detected by infrared analysis. The intensity of an infrared absorption peak at a specific wavelength is a definite and reproducible function of the amount of material in the sample beam. Hence, the absorption intensity is related to the amount of a given material in the sample.

Applications of infrared spectroscopy

An infrared spectrophotometer in operation is shown in figure 10. The Public Roads laboratory has used infrared analysis for many highway materials. One such application has been the identification of commercial concrete retarders. Because such materials are sold under different proprietary trade names, it becomes important for the purchaser to assure himself that the product is uniform in composition from batch to batch. This can be conveniently and rapidly done by infrared analysis, and long-term or involved physical testing of each batch of product purchased is not necessary.

Infrared spectroscopy provides an ideal and rapid tool, as well as one of the surest methods, for the analysis of organic substances of all types. With some limitations, it is also applicable to the analysis of inorganic materials. The sample can be in the form of a solid, liquid, or gas, and the complete analysis of a material is extremely rapid. Generally, quantitative determinations based on the amount of absorption are accurate to within plus or minus 5 to 10 percent of the amount of the constituent present.

Sample size can be very small—as little as 1 mg., less if necessary. Very little sample preparation is required, except that water or moisture must first be removed from the sample. Only minutes are required for a complete recording of the spectrum. Some States have used infrared spectral analysis for the identification of paint vehicles. Modern-day paint resins are so complex that they almost defy identification by use of ordinary chemical methods. Therefore, infrared has
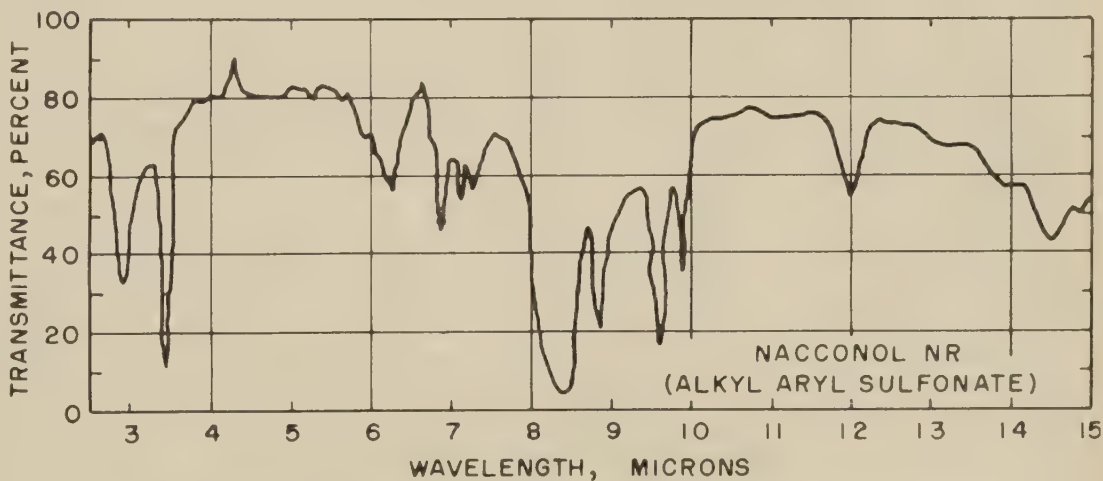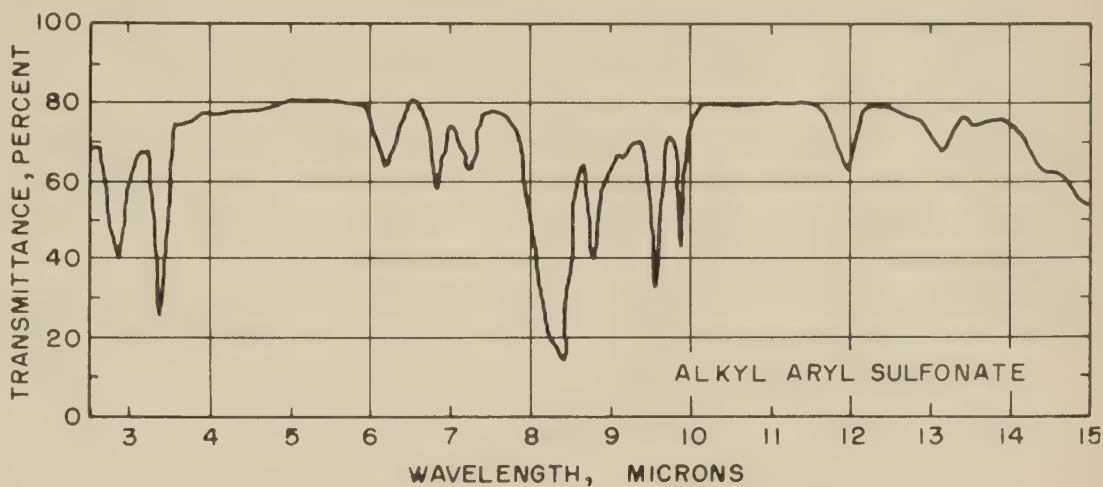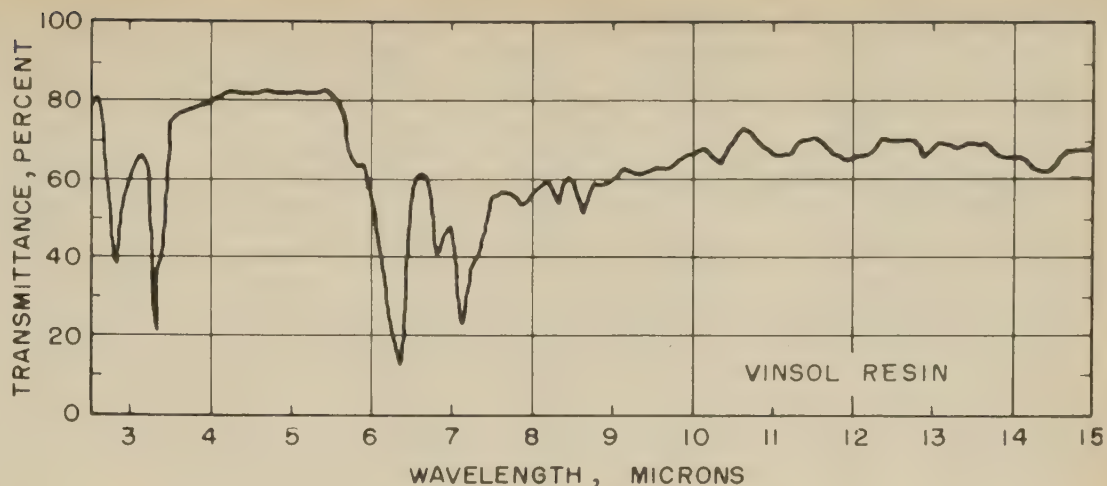

Figure 14.—Infrared spectra of concrete air-entraining admixtures.

become a valuable method for use in checking supplies of traffic paints against the original paint supplied for the performance tests. Significant differences in composition can be clearly demonstrated in minutes by infrared analysis; whereas, the detection of such differences by chemical means would require days— if they could be detected at all. Figure 11 shows the spectra of different paint resins used in traffic paints.

Infrared is also applied in a similar way to organic materials that are used as concrete admixtures. The infrared patterns of several different classes of retarders are shown in figure 12. Notice that the three spectra are substantially different and that each is characteristic for that proprietary product. Figure 13 shows how infrared can be used as a check on product uniformity. Each spectrum represents a different lot of the same pro-
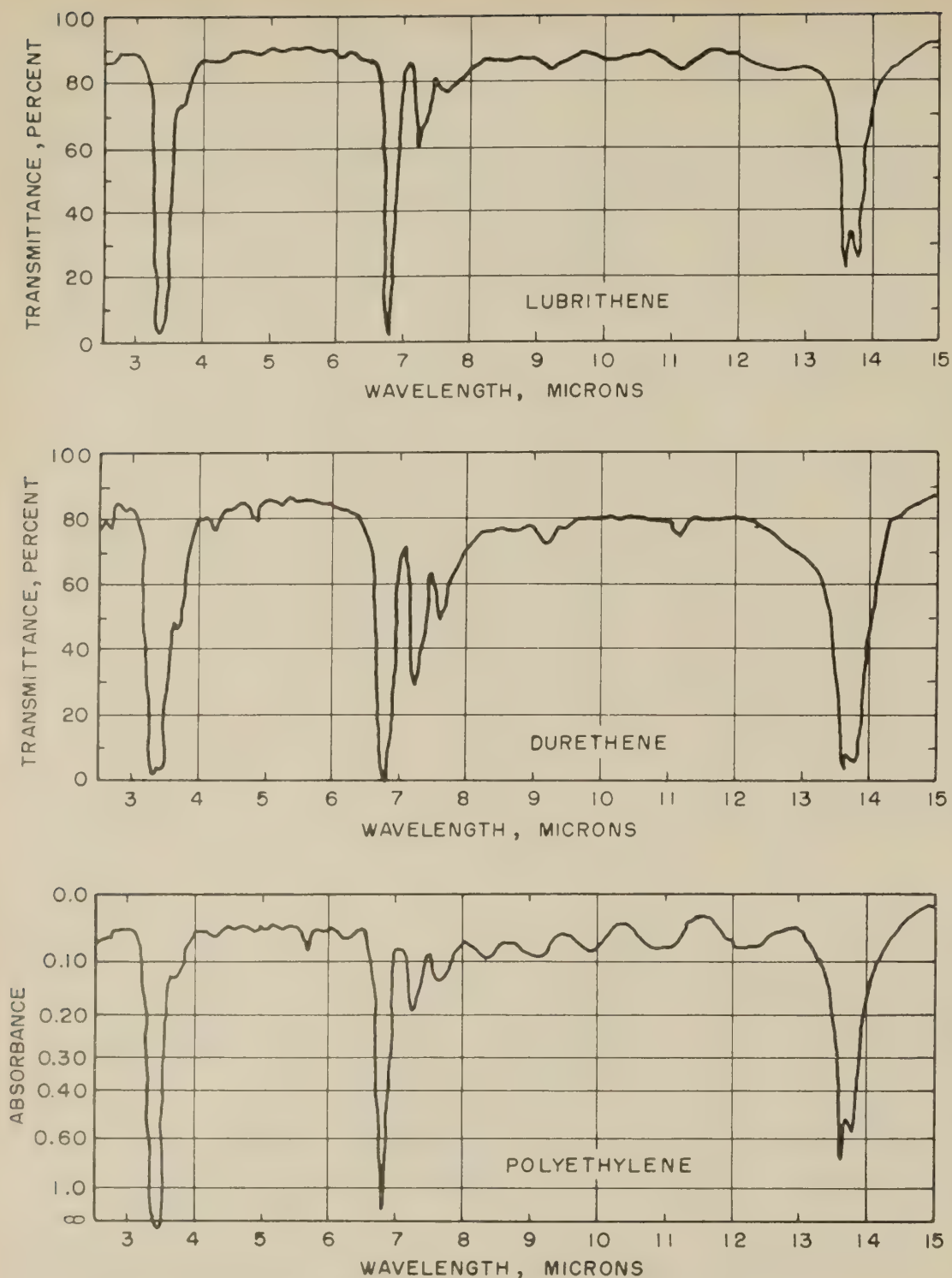
Figure 15.—Infrared spectra of plastic curing materials for concrete.

Typical infrared spectra of asphaltic constituents, separated from asphalt by chromatographic methods, are shown in figure 18

Instrumentation

Infrared instruments range in price from $5,000 to $25,000. A model in the lower price range is generally considered adequate for the purposes discussed. Infrared equipment can be economically justified where concern is either with research problems and the chemical nature of organic materials or the control of chemical uniformity of organic trade products.

X-ray Diffraction

X-ray diffraction is used to analyze crystalline materials in the solid state. When the crystalline material is irradiated with a monochromatic beam of X-rays, the different planes of atoms within the sample will diffract the X-ray beam at angles determined by the spacing between the planes. These diffracted beams can be recorded on a film placed concentrically around the sample, and the resultant image is called an X-ray diffraction pattern. This pattern is unique for each material irradiated and varies according to the characteristics. The instrument is usually further refined to provide quantitative results by employing a counter and the results obtained are in the form of patterns similar to that for X-ray fluorescence shown in figure 19 The location or lateral displacement of the peaks qualitatively establishes the nature of the material, and the height of the peaks is used as a quantitative measure of the crystalline constituents.

In operation, a small powdered sample is inserted in the instrument and the quantitative X-ray diffraction pattern is recorded automatically within 30 minutes. No special preparation normally is required for ordinary solid samples.

Application and instrumentation

X-ray diffraction techniques are applicable to studies of highway materials such as soils, clays, and aggregates. By use of this technique, the mineralogical nature of the material may be evaluated. X-ray diffraction may be used in soils and soil stabilization studies to evaluate the clay mineral nature of the soil and thereby assist in evaluation of the potential soil or subgrade properties. Siliceous minerals such as quartz and tridymite or calcareous minerals such as calcite and dolomite may be distinguished from each other, as well as identified in aggregates; this identification can be helpful when knowledge of the mineral nature of the aggregate is important. Each mineral present can be quantitatively estimated to the nearest 5 percent of the sample

prietory product. The position of the peaks as well as the shapes of the curves are substantially the same, thus giving assurance that the product is uniform.

The list of both organic and inorganic materials that can be analyzed by infrared spectroscopy is almost endless and many of these materials are of interest to highway laboratories. In addition to those already mentioned, present-day practical applications may be made to materials such as air-entraining agents, herbicides, epoxy resins, silicones, plastic sheeting and membrane curing materials, synthetic rubber water-stops, clays, and other minerals. The infrared patterns of some of these materials are shown in figs. 14–17.

The infrared spectrophotometer is also a valuable tool in the continuing research on the nature and composition of asphalts.

The cost of X-ray diffraction instrumentation is approximately $25,000. At the present time, these instruments are used by highway and university laboratories in connection with research investigations of portland cement, soils problems, or other special investigations of a nonroutine nature as to the mineralogical nature of highway materials. Unless a laboratory is concerned with such problems regularly, the cost of the instrument probably could not be justified.

X-ray Fluorescence

The principle of X-ray fluorescence is rather involved. It is based on changes in the energy levels of the electrons of the atoms that cause X-ray radiation or fluorescence. These fluorescent X-ray photons, when identified by wavelength measurements, characterize the element, and their frequency of occurrence is quantitatively proportional to the amount of the element present. The type of spectrum obtained is similar to those obtained by other X-ray techniques and is illustrated in figure 19.

X-ray fluorescence is suitable for analyzing either liquid or solid samples and is useful for the identification and quantitative determination of the elements that are present in an inorganic material. At the present time, application of this technique is limited to elements having an atomic number of 12 or more—12 is the number for magnesium. Therefore, analyses for elements such as sodium, oxygen, nitrogen, carbon, lithium, hydrogen, and a few others cannot now be made.

Quantitative accuracy of results obtained by the X-ray fluorescence technique is about 1 percent of the constituent present. Accuracy is even better when the approximate amounts of the other elements present in the sample are known so that suitable standards can be used for calibration. Use of X-ray fluorescence is not limited to the quantitative analysis of only the minor constituents of a material as is arc and spark spectroscopy; its greatest utility is and will be in determining the quantitative amounts of major elemental constituents present in a material. Sample preparation requires about 15 minutes, and a quantitative determination for each element also requires approximately 15 minutes. It takes about 1 hour to qualitatively scan the entire spectrum for the presence of all possible elements, but routine analysis of specific materials can be conducted in approximately 30 minutes.

Application and instrumentation

Examples of materials that can be analyzed at the present time by X-ray fluorescence include the chemical elements in steel, alloys, and paint pigments. Research studies are now being conducted by the National Bureau of Standards and other organizations to determine its usefulness in the analysis of portland cement. At the present time, its
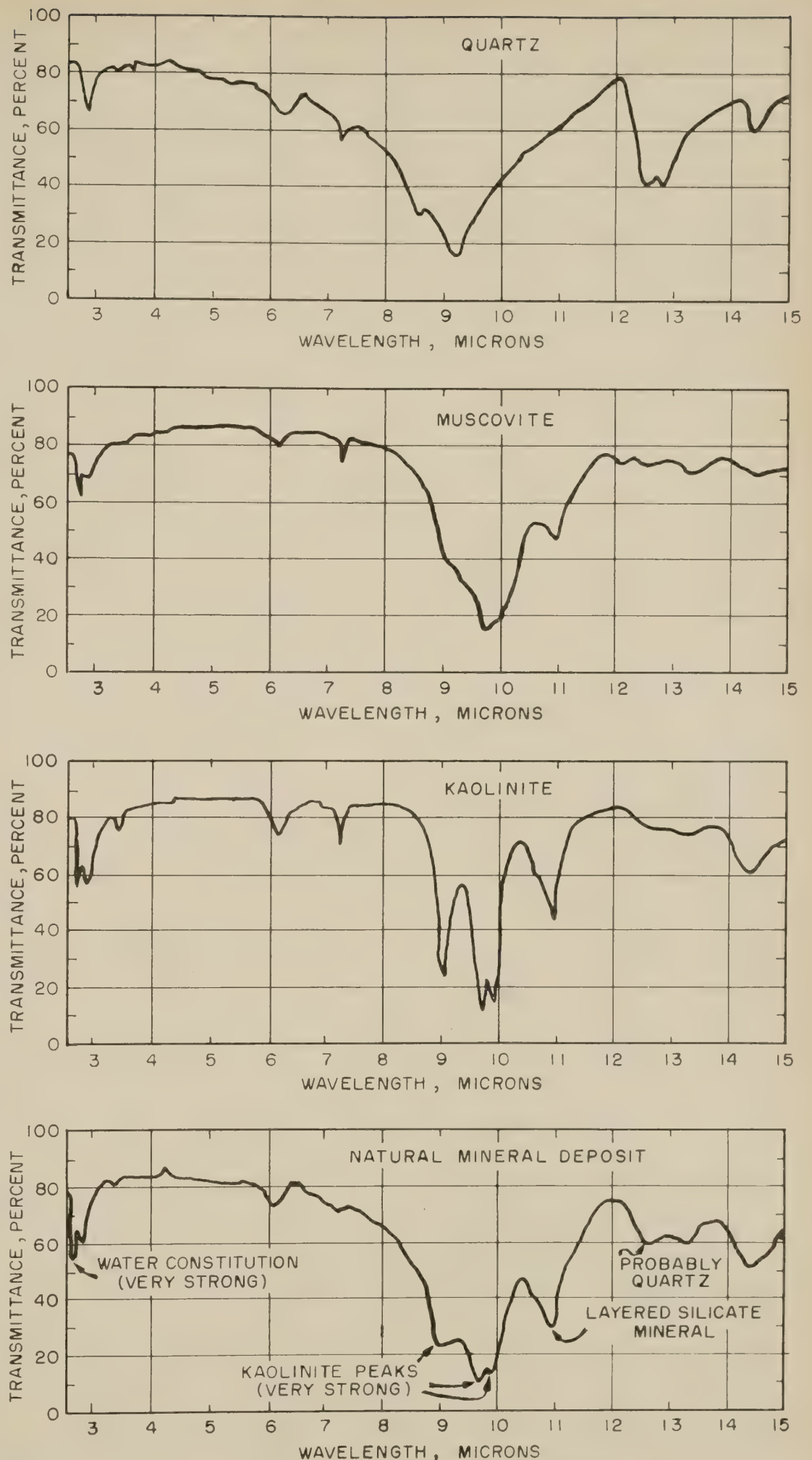

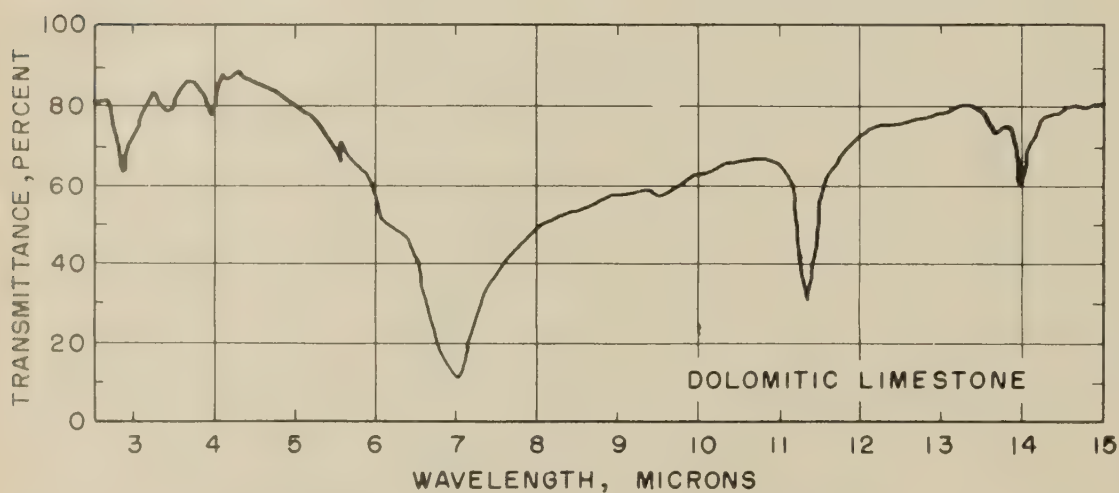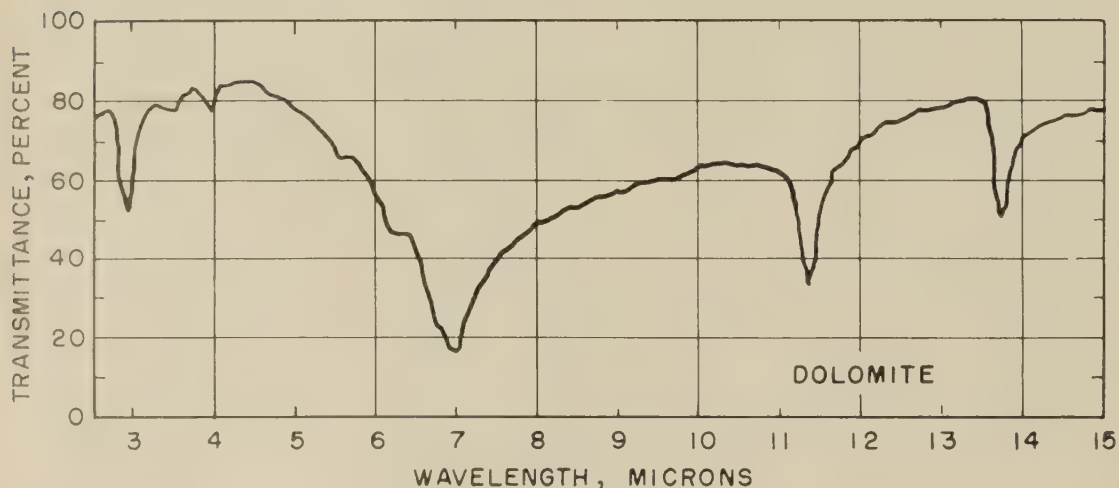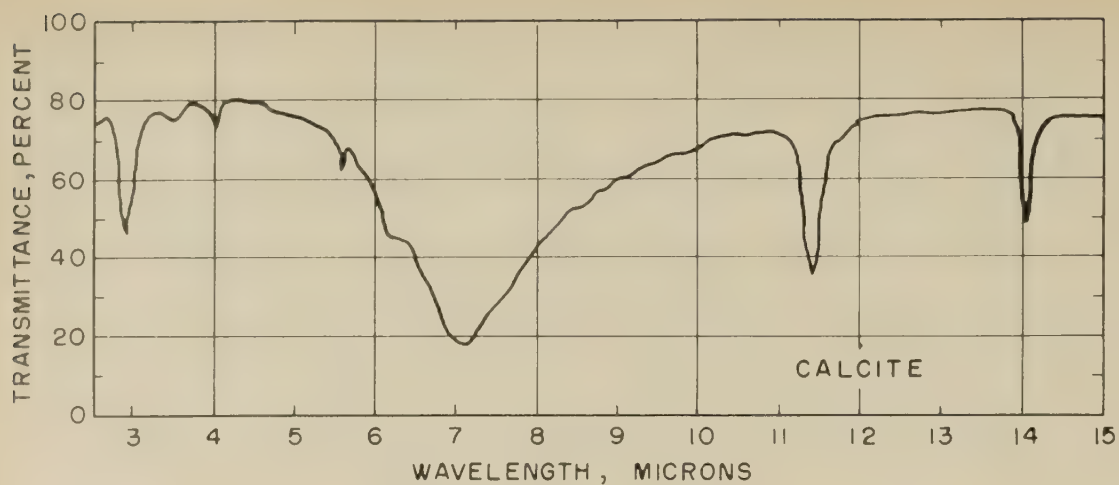Figure 16.—Infrared spectra of clays and minerals.

CALCITE

DOLOMITE

DOLOMITIC LIMESTONE

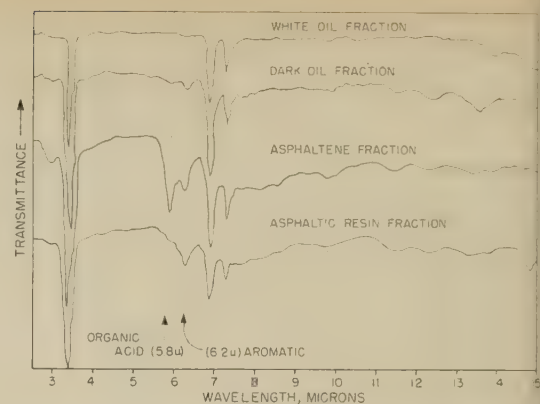Figure 17.—Infrared spectra of carbonate minerals.

Figure 18.—Infrared spectra of components of asphalt.

future use for X-ray fluorescence appears most promising for the analysis of large volumes of specific products that have a rather uniform nature. The cost of such instruments ranges from a minimum of $5,000 to more than $45,000, depending upon the channels or selectors provided for the different elements.

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(1) A Short Method for the Flame Photometric Determination of Magnesium, Manganic, Sodium, and Potassium Oxides in Portland Cement, by C. L. Ford, ASTM Bulletin 250, Dec. 1960, pp. 25–29.

(2) Flame Photometric Determination of Manganese in Cement, by J. J. Diamond, Analytical Chemistry, vol. 28, No. 3, March 1956, pp. 328–329.

(3) Flame Photometric Determination of Magnesium Oxide in Portland Cement, by T. C. Wilson and N. J. Krotinger, ASTM Bulletin 189, April 1953, pp. 56–58.

(4) Water Reducing Retarders for Concrete—Chemical and Spectral Analyses, by W. J. Halstead and Bernard Chaiken, PUBLIC ROADS, vol. 31, No. 6, Feb. 1961, pp. 126–135

(5) Standard Method of Test for Phthalic Anhydride Content of Alkyd Resins and Esters Containing Other Dibasic Acids (Spectrophotometric), Method Designation: D 1307, in ASTM Standards 1958, Part 8, Paint, Naval Stores, Aromatic Hydrocarbons, Coal and Coke, Gaseous Fuels, Engine Antifreeze, pp. 602–606.

application to this material is not considered practical for rigid control purposes but such application is expected to become a reality in a little more than 5 years. This would mean that an analysis now requiring several days could be completed in from 30 minutes to an hour.

The instrument is usually set up for the analysis of a particular material—a specific alloy, portland cement, or special steel. Consequently, in its present stage of development, it is impracticable to adjust the same instrument for use on a cement, then a paint pigment, and then an alloy, etc. Therefore, the

Figure chart (X-ray fluorescence spectrum):

INTENSITY (vertical axis: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100)

ZINC 5.76 PCT.

ZINC

COPPER

ZINC

ZIRCONIUM 0.64 PCT.

IRON 0.003 PCT.

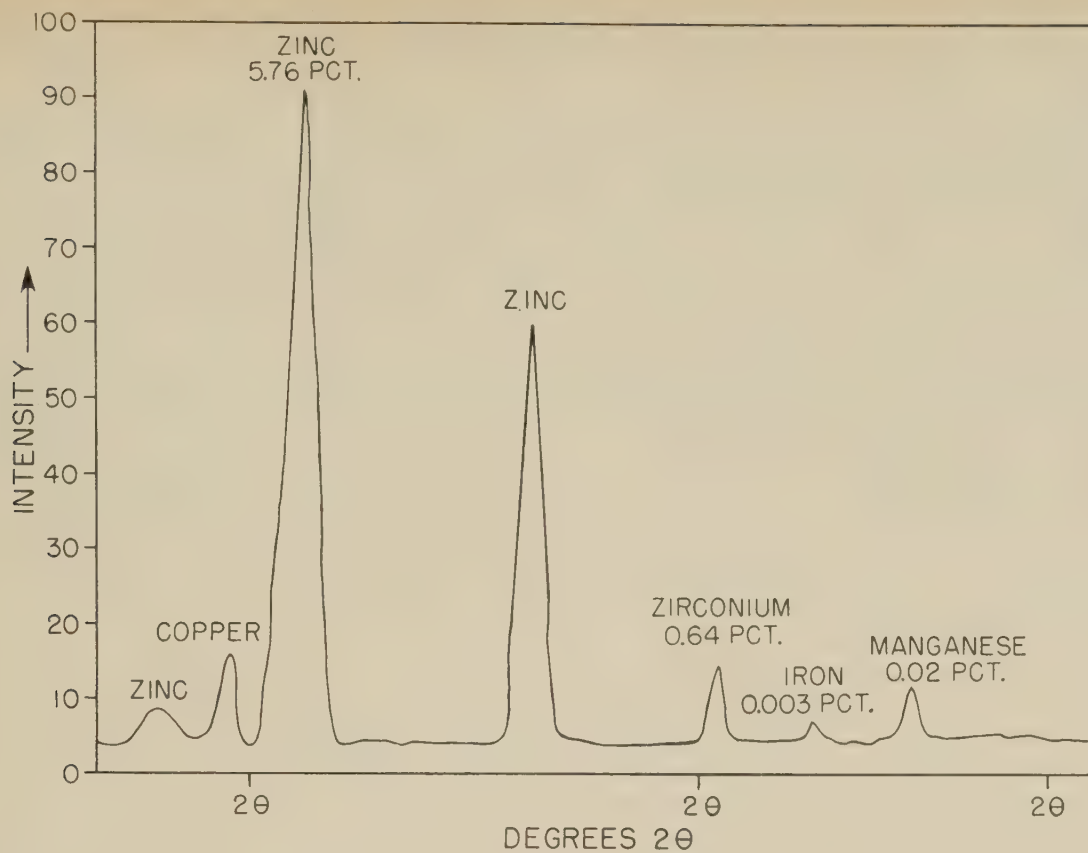MANGANESE 0.02 PCT.

2θ   2θ   2θ

DEGREES 2θ

Figure 19.—X-ray fluorescence spectrum of magnesium alloy.

Table 1.—Spectroscopy methods presently applicable to routine control of highway materials [1]

Type of instrument	Approximate cost including accessories	Fields of application — Material	Constituent determined and/or purpose of test	Type of determination	Average attended time required per sample [4] — For sample preparation	For instrumental evaluation and calculation	Total	Average elapsed time for analysis [7]	Quantitative accuracy; percent of constituent present — Routine	Possible
					Minutes	*Minutes*	*Minutes*	*Days*	*±Percent*	*±Percent*
Spectrophotometer: (manual type)	$2,500									
Ultraviolet light	(2)	Paint vehicles	Alkyd resin	Quantitative	5–30	10	15–40	1	2	0.5
		Concrete retarders	Lignosulfonate	___do	5–30	10	15–40	1	2	0.5
		Concrete air-entraining admixtures.	Vinsol resin, Darex, etc.	___do	5–30	10	15–40	1	2	0.5
Visible light		Fertilizer	Phosphoric acid	___do	5–30	5	10–35	5 1	2	0.5
		Cement, slag	Titanium dioxide	___do	5–30	5	10–35	5 1	2	0.5
		___do	___do	___do	5–30	5	10–35	5 1	2	0.5
		Concrete aggregates	Alkali reactivity, chemical test for silica.	___do	5–30	1	10–35	5 1	2	0.5
		Steel	Minor constituents	___do	5 5–30	5 5	5 10–35	5 1	2	0.5
		Copper & aluminum alloys	___do	___do	5 5–30	5 5	5 10–35	5 1	2	0.5
Flame Photometer	3 $500–2,500	Cement	Alkalies	___do	5–15	5	10–20	½	5	1.0
		Fertilizer	Potash	___do	5–15	5	10–20	½	5	1.0
		Rock salt (for ice removal)	Sodium chloride	___do	5–15	5	10–20	½	5	1.0
Infrared spectrophotometer. (automatic rerecording)	$5,000–25,000	Concrete retarders, water-reducers, air-entraining admixtures, curing materials, and rubber and synthetic water stops.	Identification and/or uniformity of product.	Qualitative and semiquantitative	5–20	15–30	20–50	1	10	2.0
		Herbicides	___do	___do	5–20	15–30	20–50	1	10	2.0
		Epoxy resins	___do	___do	5–20	15–30	20–50	1	10	2.0
		Paint vehicles and pigments	___do	___do	5–20	15–30	20–50	1	10	2.0
		Silicones	___do	___do	5–20	15–30	20–50	1	10	2.0
		Carbonate aggregates	___do	___do	5–20	15–30	20–50	1	10	2.0
		Clays and other minerals	___do	___do	5–20	15–30	20–50	1	10	2.0
		Bituminous mineral fillers	___do	___do	5–20	15–30	20–50	1	10	2.0
Arc and spark spectrograph. (Photographic plate)	$40,000	Alloys of aluminum, copper, magnesium, nickel, lead, tin, and zinc.	Minor alloying constituents.	Quantitative	6 0–10	6 5–50	6 5–60	6 1–3	10	1.0
		Steel	___do	___do	6 0–10	6 5–50	6 5–60	6 1–3	10	1.0
		Paint pigments	Minor constituents	___do	6 0–10	6 5–50	6 5–60	6 1–3	10	1.0

[1] Date shown in table are general estimates. Considerable variation in estimates should be expected depending on specific conditions encountered.
[2] Available as accessory to manually operated spectrophotometer and is included in cost shown for this instrument.
[3] Also available as accessory to some manual spectrophotometers.
[4] Assuming large volume of similar samples to be tested.
[5] Time shown is for each alloying constituent in metals.
[6] Time shown is for all of the alloying or minor constituents present.
[7] Time from beginning of work on a specific sample until analysis is complete for that sample under routine control conditions.

New Publications

INTERSTATE SYSTEM ROUTE LOG AND FINDER LIST

The Bureau of Public Roads has recently published *Interstate System Route Log and Finder List*, a 16-page leaflet that explains the numbering system of the National System of Interstate and Defense Highways and presents (1) a list of main Interstate Highway System routes, the mileage in each State, and key cities the routes pass through; (2) a list of radial, circumferential, and spur Interstate routes; and (3) a list of major cities served by the Interstate System. A small-scale map of the System is also included.

These listings provide a means for finding the general locations of each Interstate route and for finding the numbers of the routes that serve each major city. Because many portions of the Interstate System are not yet built, the leaflet will not serve as a touring guide, nor is it intended for that purpose. It will be useful, however, for many other purposes.

This leaflet is available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., for 10 cents a copy.

HIGHWAY STATISTICS, 1961

The Bureau of Public Roads, U.S. Department of Commerce, has published a new 150-page bulletin, *Highway Statistics, 1961*, the 17th in the annual series that presents statistical and analytical tables of general interest on motor fuel, motor vehicles, highway-user taxation, State and local highway financing, road and street mileage, and Federal aid for highways.

Highway Statistics, 1961, may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., for $1.00 a copy. Some of the previous annual issues of the series and the summary to 1955 are also available from the Superintendent of Documents; a list of available issues is carried on the inside back cover of this magazine.

The Road to Better Roads

(Third AASHO Road Test Film)

A third film on the AASHO Road Test has been released by the Bureau of Public Roads, U.S. Department of Commerce. Entitled, *The Road to Better Roads*, this film is a 16-mm. color and sound production that has a running time of about 14 minutes. This film is a nontechnical description of the $27 million highway research project conducted at Ottawa, Illinois during the years 1956 to 1961.

The Bureau of Public Roads has produced two previous films designed to acquaint engineers with the technical details of the project's materials, construction, test procedures, and results. Information on these films has been published in PUBLIC ROADS, volume 32, No. 3, p. 63, and No. 5, p. 112, respectively.

The latest film is considered suitable for showing to citizens groups, highway-oriented organizations, or legislative bodies. A Public Roads spokesman has suggested that the film might be particularly useful to State highway officials in explaining the background of State-conducted research designed to expand upon the results of the AASHO Road Test.

The Road Test was a research project designed to study the performance of different highway pavements and bridges under controlled truck and traffic loading. The test was sponsored by the American Association of State Highway Officials and financed by the States, Public Roads, and some industry groups. The Department of Defense cooperated in the project, which was administered by the Highway Research Board of the National Academy of Sciences—National Research Council.

Prints of the film, *The Road to Better Roads*, may be borrowed by contacting one of the Division Offices of the Bureau of Public Roads, one of which is located in each State capital. Requests may also be submitted directly to the Photographic Section, Bureau of Public Roads, Washington 25, D.C. There is no charge other than for express or postage fees for booking the film. Requests should be submitted well in advance of the desired screening date, and alternate dates indicated if possible. Immediate return of the film after each booking is required.

PUBLICATIONS
of the Bureau of Public Roads

A list of the more important articles in PUBLIC ROADS *and title sheets for volumes 24–31 are available upon request addressed to Bureau of Public Roads, Washington 25, D.C.*

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D.C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

Annual Reports of the Bureau of Public Roads:

1951, 35 cents. 1955, 25 cents 1958, 30 cents. 1959, 40 cents. 1960, 35 cents. 1962, 35 cents. (Other years, including 1961 report, are now out of print.)

REPORTS TO CONGRESS

Factual Discussion of Motortruck Operation, Regulation and Taxation (1951). 30 cents.

Federal Role in Highway Safety, House Document No. 93 (1959). 60 cents.

Highway Cost Allocation Study:
First Progress Report, House Document No. 106 (1957). 35 cents.

Final Report, Parts I–V, House Document No. 54 (1961). 70 cents.

Final Report, Part VI: Economic and Social Effects of Highway Improvement, House Document No. 72 (1961). 25 cents.

The 1961 Interstate System Cost Estimate, House Document No. 49 (1961). 20 cents.

U.S. HIGHWAY MAP

Map of U.S. showing routes of National System of Interstate and Defense Highways, Federal-aid Primary Highway System, and U.S. Numbered Highway System. Scale 1 inch equals 80 miles. 25 cents.

PUBLICATIONS

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and A New Graphical Evaluation Chart (1962). 25 cents.

America's Lifelines—Federal Aid for Highways (1962). 15 cents.

PUBLICATIONS—Continued

Classification of Motor Vehicles, 1956–57 (1960). 75 cents.

Design Charts for Open-Channel Flow (1961). 70 cents.

Federal Laws, Regulations, and Other Material Relating to Highways (1960). $1.00.

Financing of Highways by Counties and Local Rural Governments: 1942–51 (1955). 75 cents.

Highway Bond Calculations (1936). 10 cents.

Highway Capacity Manual (1950). $1.00.

Highway Statistics (published annually since 1945):
1955, $1.00. 1956, $1.00. 1957, $1.25. 1958, $1.00. 1959 $1.00. 1960, $1.25. 1961, $1.00.

Highway Statistics, Summary to 1955. $1.00.

Highway Transportation Criteria in Zoning Law *and* Police Power and Planning Controls for Arterial Streets (1960). 35 cents.

Highways of History (1939). 25 cents.

Hydraulics of Bridge Waterways (1960). 40 cents.

Increasing the Traffic-Carrying Capability of Urban Arterial Streets: The Wisconsin Avenue Study (1962). 40 cents. Appendix, 70 cents.

Interstate System Route Log and Finder List. 10 cents.

Landslide Investigations (1961). 30 cents.

Manual for Highway Severance Damage Studies (1961). $1.00.

Manual on Uniform Traffic Control Devices for Streets and Highways (1961). $2.00.

Parking Guide for Cities (1956). Out of print.

Peak Rates of Runoff From Small Watersheds (1961). 30 cents

Road-User and Property Taxes on Selected Motor Vehicles, 1960. 30 cents.

Selected Bibliography on Highway Finance (1951). 60 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1958: a reference guide outline. 75 cents.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP–61 (1961). $2.25.

Standard Plans for Highway Bridges (1962):
Vol. I—Concrete Superstructures. $1.00.
Vol. II—Structural Steel Superstructures. $1.00.
Vol. III—Timber Bridges. $1.00
Vol. IV—Typical Continuous Bridges. $1.00.

The Identification of Rock Types (revised edition, 1960). 20 cents.

The Role of Aerial Surveys in Highway Engineering (1960). 40 cents.

Transition Curves for Highways (1940). $1.75.