CURRENT PROBLEMS IN RESEARCH

Intense Rapid Heating with Flash Discharge Lamps

Heat pulses equivalent to those near atomic blasts may be produced safely with modest apparatus.

L. S. Nelson

The flash discharge lamp is a simple light source, yet it produces heat equivalent to that a few hundred yards away from an atomic explosion (*1*). Naturally, the effect of such heating on solid materials is tremendous. In this article, after first describing the characteristics of flash lamps that enable us to bring these bursts of energy safely into the laboratory, I describe some of the dramatic chemical and physical changes that have been brought about in and around solids with these lamps.

For over two decades now, flash discharge lamps have been in wide use in photography for tasks ranging from pictorially stopping bullets in flight to aerial photography. This is mainly due to the pioneering work of electrical engineer Harold E. Edgerton of Massachusetts Institute of Technology. In the last decade, chemists and physicists have discovered that the pulses of light from these lamps have a strong photochemical action on gases and liquids, and they have used them to prepare large instantaneous quantities of molecular fragments called free radicals, about which more is said in a subsequent section.

Recently, however, it has been found that the light pulses from flash lamps heat properly prepared solid materials very intensely and rapidly. Temperatures of several thousand degrees—white hot—can be reached safely in a few milliseconds in almost any solid, an effect previously obtainable only in explosions. This has opened many new paths for research to the chemist, physicist, and metallurgist, and in this article I describe a few of the experiments my co-workers and I have performed while exploring this method. Most of this work has been done collaboratively at Bell Telephone Laboratories by J. L. Lundberg, N. A. Kuebler, J. G. Kay, M. Y. Hellman, and myself.

In principle, the flash lamp is not complicated, consisting basically of a transparent tube, usually of fused quartz, into the ends of which electrodes are sealed. The tube is filled with a gas, usually an inert gas like xenon, at about one-tenth atmospheric pressure. The details of constructing reliable flash lamps in many shapes have been well worked out by the electronics manufacturers, mainly because of their use in photography and, more recently, for optical maser devices (*2*). All of the experiments described here have been performed with easily obtainable commercial flash tubes, a few of which are shown in Fig. 1. Larger and smaller tubes can be made also, and thus the experimenter has available a wide variety of lamps for many purposes.

Notice that these lamps are not of particularly heavy construction, yet they have a very large output. This is accomplished by a simple trick often used by the electrical engineer—pulse operation. By operating an electrical device for only brief periods, it is possible to drive it many times beyond the capacity it would have if operated continuously. Thus, a wire which will carry only a 5-ampere steady current can be safely made to carry a 5000-ampere current for 1 millisecond without melting or evaporating. This technique is used frequently to produce intense microwave pulses for radar, very high magnetic fields, and many other short-time electrical phenomena.

The flash lamp is normally operated by attaching across its electrodes a capacitor charged to a high voltage. When the circuit is completed, a single short, energetic pulse of current passes from the capacitor through the flash tube, producing a single short, energetic pulse of light. Since the pulse operation cannot be repeated very soon after the flash without damaging the lamp, it is not necessary to charge the capacitor very rapidly. Thus, a high-voltage power supply with a rather low current output can be used, and of course, the lower the current demanded from a power supply, the less bulky and costly it is.

Thus, the apparatus needed for producing large heating effects with flash lamps is relatively modest. A typical circuit for such work is shown in Fig. 2. In this case the lamp is operated with the capacitor charged to a voltage below the spontaneous breakdown voltage of the lamp. The circuit is completed here by ionizing the gas in the lamp with a high voltage "tickling" pulse from a Tesla coil. When the lamp is operated above its spontaneous breakdown voltage, one must use mechanical switches, spark gaps, or large thyratrons, which are really electronic switches.

The Lamp as a Heat Source

It is frequently necessary, in flash-heating work, to measure the amount of heat a flash lamp will produce. A very simple way is to expose a block of graphite to the flash and measure its rise in temperature (*3*). We have drilled a tiny hole in the end of a ¼-inch graphite rod and have inserted snugly therein a fine thermocouple. When the thermocouple is attached to a recorder, a temperature jump occurs when a pulse of light falls on the rod. This jump can then be used to calculate the amount of light energy which fell on each square centimeter of the rod. Now, if we know the duration of the flash of light, we can also calculate the rate of energy output, called the power in electrical terms but in optical terms called the irradiance. Figure 3 (bottom) is a plot of the amount of heat per square centimeter which can be obtained at the center of a commercial helical flash lamp surrounded by a cylindrical metallic reflector when flashed at various capacitor energies. (The electrical energy stored in a charged capacitor is ½ CV^2, where C is the capacitance in farads and V is the voltage to

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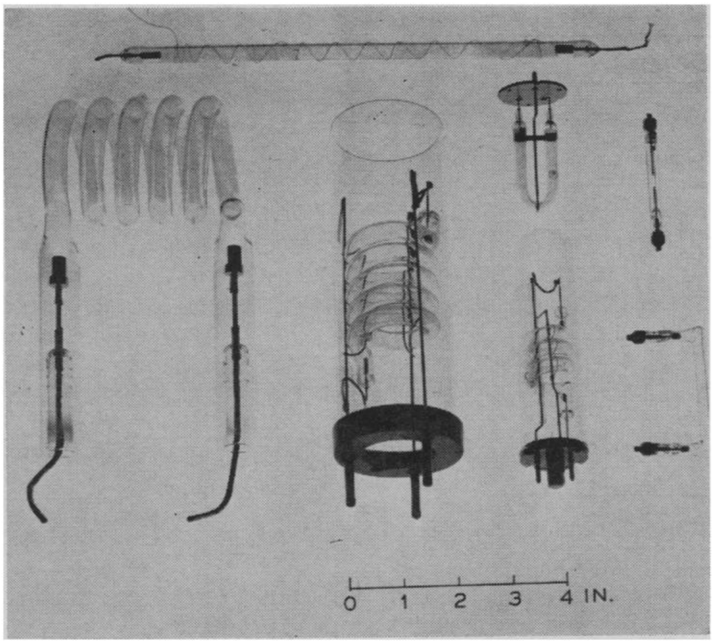


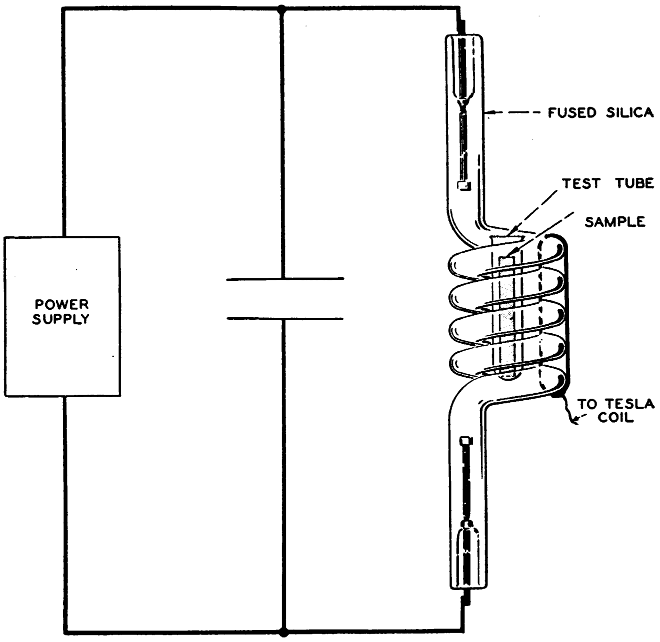


Fig. 1 (left). Commercially available flash discharge lamps. Fig. 2 (right). A typical circuit for flash discharge lamps. This uses high-voltage "tickling" from a Tesla coil to initiate the flash.

which the capacitor is charged. Typical values for C and V might be 100 microfarads and 4000 volts.) Figure 3 (top) is a plot of the maximum irradiances (rates of energy output) obtained from the same lamp. It should be noted that maximum irradiances of about 20 kilowatts per square centimeter (for the short pulse times) are routinely obtained with flash lamps, while the largest solar furnaces seldom achieve irradiances of more than 2 or 3 (in continuous operation).

Why do we not use flash lamps, then, for every type of heating, as a sort of universal furnace? Because the amount of heat in any one flash is not large enough to raise the temperature of a large chunk of a solid very high. For example, the temperature of the graphite rod of ¼-inch diameter that we used to measure the flash-lamp outputs did not rise above 100°C, even though the rod was exposed to these tremendous short-kilowattage bursts.

How, then, do we heat solids with flash lamps? Simply by dividing the solid into very tiny bits. This is illustrated in a somewhat simplified manner in Fig. 4, which shows the temperature rises to be expected as a cube of graphite 1 centimeter on a side is cut into progressively thinner slices, all of which are exposed uniformly to the flash of light. Let us assume that the heat capacity of 1 cubic centimeter of graphite is 0.5 calorie per degree centigrade (that is, every time one-half calorie enters the graphite cube, the temperature of the cube rises 1 degree centigrade). Also, let us use a flash lamp that irradiates each square centimeter of the graphite with 4.2 joules (see Fig. 3), or 1 calorie per flash (this unit is used here for easy calculation). Notice that every time the cube is sliced, the area increases by 2 square centimeters. That is, as the slices become thinner, the total absorbing area of the graphite increases rapidly. The total energy absorbed depends directly on the area exposed to the flash, and thus also increases rapidly. By the time the cube is sliced 1000 times, the energy absorbed is great enough to raise the temperature of the graphite slices into the several-thousand-degree region. And finally, since each slice of the graphite is irradiated uniformly and independently of the others, all the slices will reach the same temperature during the flash. So, whether there is one slice or whether there are ten or a thousand slices being irradiated with a single flash, the rise in temperature of each isolated slice will depend only on its thickness and not on how many neighbors it has.

Absorbing particles with shapes other than a flat sheet heat just as well in the flash as those of flat-sheet form, as long as at least one dimension of the absorber is small. In fact, much of the work in this field has been done with spheres (powders) and small cylinders (wires, fibers, filaments). In Fig. 5 are plotted the results of a more exact calculation of the temperature rises of particles of spherical, cylindrical, and thin-sheet form. As a rule of thumb, we consider the dimension 100 microns (0.1 mm) to be that below which flash-heating activity begins, although in Fig. 5 it may be seen that there is no really sharp division there. Figure 5 also shows that one cannot reach infinite temperatures just by using particles with smaller and smaller dimensions,

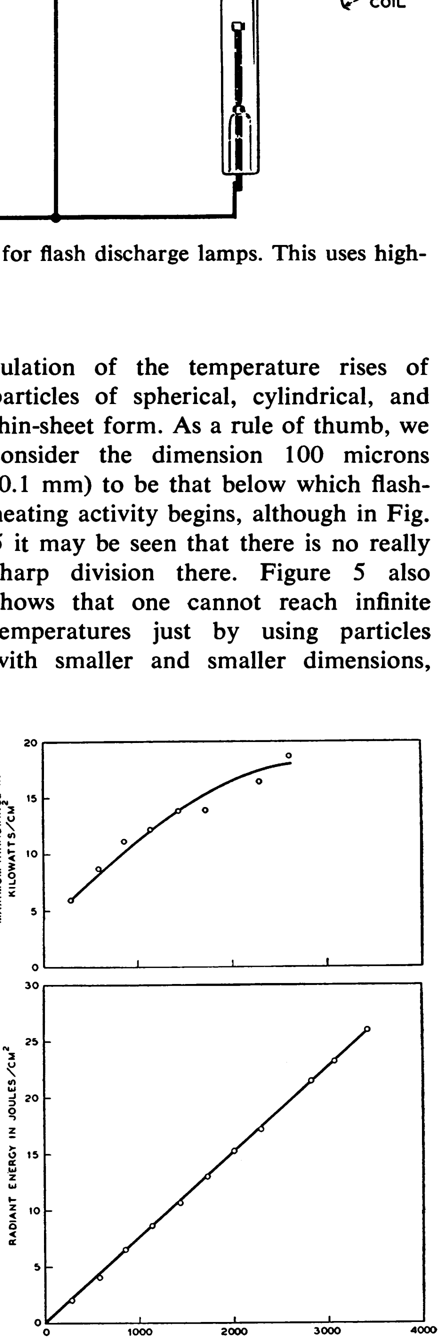
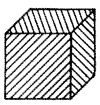
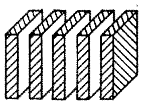
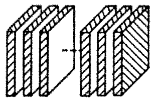
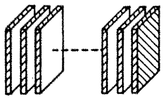


Fig. 3. Radiant energies and maximum irradiances obtained at the center of a helical discharge lamp flashed at various electrical energies.

	SLICE THICKNESS	AREA BEFORE SLICING	AREA ADDED BY SLICING	TOTAL AREA	HEAT ABSORBED	TEMPERATURE RISE
1 CM CUBE 	1 CM	6 CM^2	0	6 CM^2	6 CAL	12°C
4 CUTS 	0.2 CM	6 CM^2	8 CM^2	14 CM^2	14 CAL	28°C
100 CUTS 	∽.01 CM	6 CM^2	200 CM^2	206 CM^2	206 CAL	412°C
1000 CUTS 	∽.001 CM	6 CM^2	2000 CM^2	2006 CM^2	2006 CAL	4012°C

ASSUME: HEAT CAPACITY = 0.5 CAL/CM^3/°C; LAMP EMISSION = 1 CAL/CM^2/FLASH

Fig. 4. Stepwise computation of temperature rises of a graphite cube 1 centimeter on a side, sliced into progressively thinner slices and exposed to a 1-calorie-per-square-centimeter flash.

because eventually the particle will reradiate energy by blackbody radiation (that is, by glowing white hot) as fast as energy is absorbed, and the particle temperature will not rise further. But since the limit of these temperatures is ordinarily about 5000°C, this is not a very serious limitation at present.

In the rest of this article many of the experiments that have been performed with this heating effect are described. Most of the experiments to date have been carried out with helical flash lamps, but straight or U-shaped lamps, singly or in banks, can be used as well, as long as they produce the same amount of light energy per square centimeter per flash.

The first published work in this field was carried out at the Technische Hochschule in Switzerland by J. Eggert and his co-workers, starting in about 1953. These workers found (*4*) that when paper coated with an emulsion made from powdered metallic salts called azides was exposed to a very intense flash of light with a photographic negative interposed, the emulsion would explode selectively where the light fell. A little investigation showed that this was purely a thermal effect, due to the absorption of light by the fine azide grains in the emulsion. A good image can be formed this way, although the technique is perhaps a little too dynamic for the ordinary photographer.

Eggert's group also found that a sort of phototransfer could be made simply by placing a piece of blank white paper against a printed page and exposing the back of the blank sheet to a light flash. The light passes through the blank sheet, and the ink on the printed page absorbs the light, gets hot, and chars the white sheet where there is printing next to it but not elsewhere. Thus, a photocopy (albeit a mirror image) of the original can be made. Figure 6 shows an image formed in this way. A flash photocopying device based on this principle is currently being manufactured in the United States.

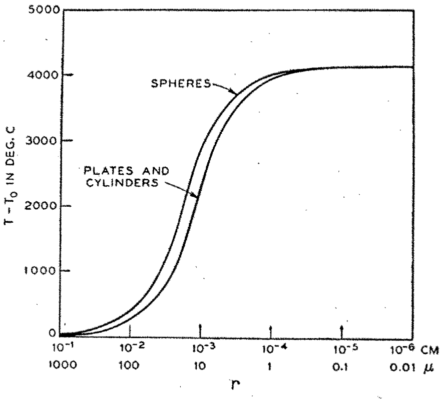


Fig. 5. Calculated temperature rises for graphite spheres, cylinders, and plates of various half thicknesses illuminated in a vacuum with a 1-calorie-per-square-centimeter flash.

In 1956, J. L. Lundberg and I, at the Bell Telephone Laboratories, discovered accidentally, and without knowledge of the Swiss work, that many different polymers irradiated with intense light pulses from flash lamps would undergo a curious spotwise charring (*5*). A piece of polyethylene, originally a smooth translucent white, was flashed in this way; it is shown in Fig. 7. This effect was found to be due to the flash heating of small absorbing particles—mostly dust and tiny metal chips from machinery—which were trapped in the bulk of the polymer during processing. Very clean polymers did not act in this way. Incidentally, very few polymers were found to be really free from this type of contamination.

On the basis of the work of Eggert's group and that of Lundberg and myself, a great many new experiments were performed in which various small-dimension solid absorbing bodies of spherical, cylindrical, and flat-sheet form were flash-heated in a vacuum, or when they were surrounded with various gaseous, liquid, or solid materials. In the following description of these I shall call the solid bodies the absorbers and the surroundings of the absorber, the matrix.

Processes Initiated by Flashes

Five types of processes initiated by flashes are discussed here.

1) Evaporation or melting of the absorber—that is, mere change of phase without producing new molecules.

2) Decomposition of the absorber—that is, production of molecules other than those present before the flash.

3) Decomposition of the matrix, induced by heating the absorber.

4) The direct reaction of the absorber and the matrix.

5) Strong heating of an absorber thinly coated with another solid or liquid—for example, carbon filaments on which a salt has been deposited. An active matrix may also be present. These reactions are complex and have not been studied very thoroughly as yet.

Reactions 3 and 4 really overlap considerably, because at temperatures in the several-thousand-degree region, there is no absorber which remains really inert. Yet, we feel, at lower temperatures in many cases the absorber does not participate in the reaction other than as a material which transfers heat to the matrix.

When finely divided metals (powders,

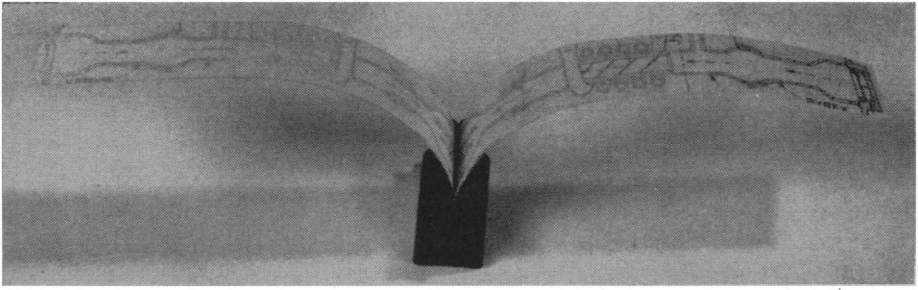


Fig. 6. Thermal phototransfer of a printed page (at right) onto a blank white sheet (at left). The pieces were held together between microscope slide glasses during the flash. Note that the phototransfer is a mirror image of the printed original. The process was devised by J. Eggert and his co-workers.

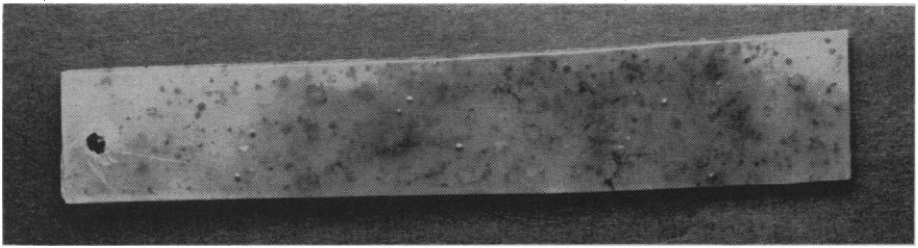


Fig. 7. A polyethylene strip flashed inside the coil of a helical lamp. Spotwise thermal degradation and gas bubbles formed around dirt particles trapped in the polymer matrix.

wires, foils) are flash-heated in a vacuum or in gases, they evaporate violently. We have studied this in tungsten, the most refractory of all metals (that is, the most stable when heated) as well as in many metals with lower boiling points, such as aluminum, copper, zinc, lead, and many others. Several frames taken with a high-speed motion picture camera (8000 frames per second) by J. G. Kay, M. Shemanski, and me show (Fig. 8) the progressive evaporation of a lead foil in air during exposure to a flash discharge.

When metal powders are suspended in a viscous liquid and flash-heated, they still evaporate, although the vapor in this case is immediately quenched and condenses into droplets of smaller size. When bismuth powder, for example, was flash-heated while suspended in a glycerine matrix, the particles, instead of averaging 40 microns in diameter, had an average diameter of 2 microns. This method can be used to prepare finer powders than can be obtained by the usual grinding and sieving.

This experiment does not work, however, when the liquid matrix boils at a low temperature. Ethyl alcohol or water, for example, cannot be used as a matrix during the evaporation of a solid because of a microscopic boiling of the liquid that seems to occur around each heated particle during the flash. This boiling, while it produces no visible bubbles, is sufficient to keep the particle cool and prevent evaporation.

When clean polymer fibers such as polyethylene or rayon are irradiated with intense light pulses, reaction 2 occurs. That is, the polymer molecules decompose during the flash. Various gaseous, liquid, and solid decomposition products have been detected in this way.

When a metal like lead is evaporated with a light flash in a gas like methane (CH_4), new molecules form, due to thermal breakdown of the gas. One of these product molecules is ethylene (C_2H_4), which has recently been detected spectroscopically by Kay, N. A. Kuebler, and me. Yet there is no evidence that the lead combines or reacts with the original methane. We think that the lead acts here only as a molecule that transfers heat into the methane, not as an active participant in the reaction.

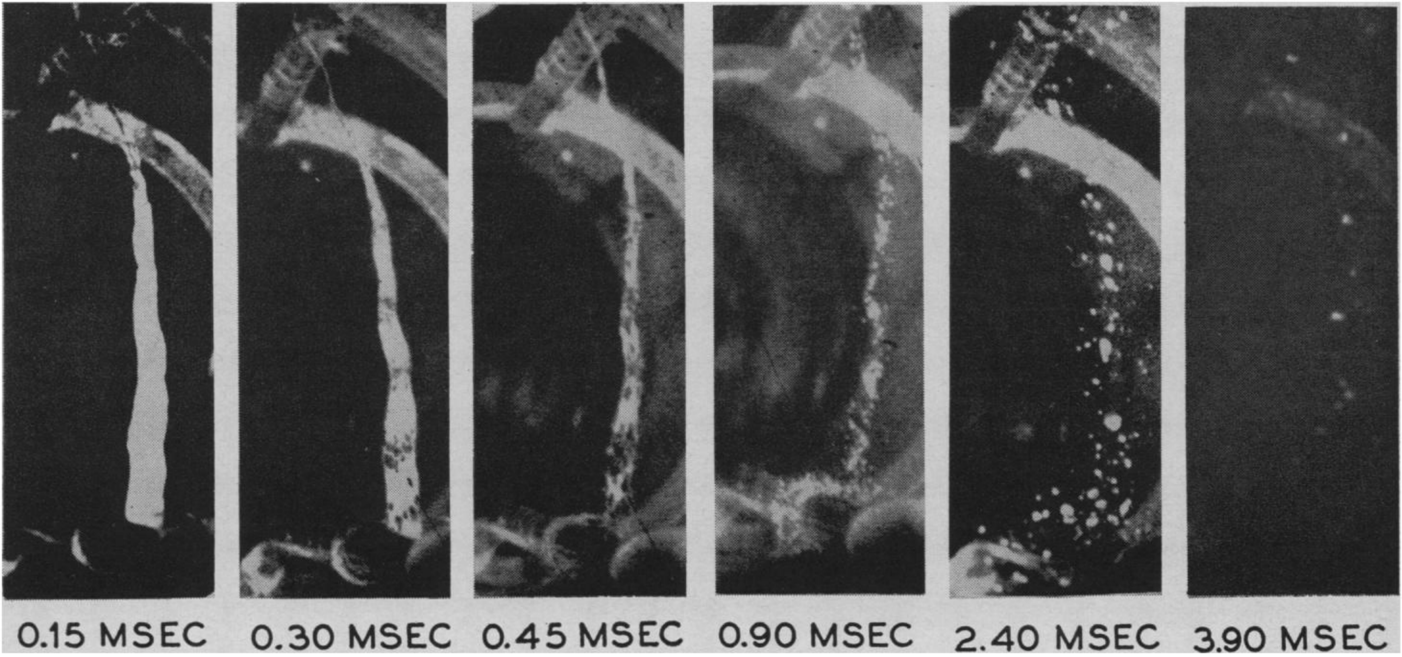


Fig. 8. Enlarged frames from a high-speed motion-picture record of lead foil evaporating during a flash. The lead is suspended at the center of a lamp helix. [J. G. Kay, M. Shemanski, L. S. Nelson]

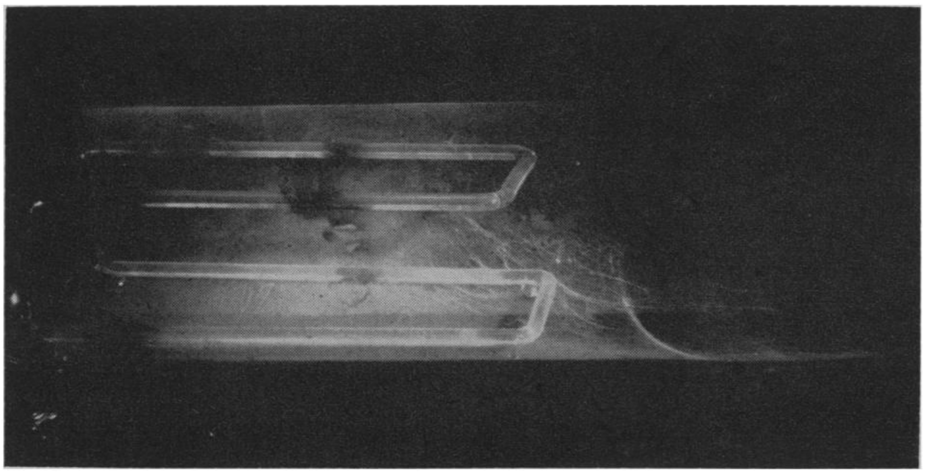


Fig. 9. Lead fluoride fibers formed when lead foils are flashed in sulfur hexafluoride, in work done by J. G. Kay, N. A. Kuebler, and L. S. Nelson.

But when the lead is flashed in the gas sulfur hexafluoride (SF_6) it does react, and a smoky white deposit of lead fluoride (PbF_2) is formed in the reaction vessel. Kay, Kuebler, and I discovered also that occasionally the lead fluoride can precipitate in a cobwebby formation, such as the one shown in Fig. 9. This is a behavior usually associated with a gas phase that is heavily supersaturated with a given molecule, in this case the PbF_2 molecule.

Another curious reaction of type 4, in which the matrix and absorber react, is that which can be induced when aluminum powder is flash-heated in chloroform in a glass test tube. The reaction products are, somewhat unexpectedly, carbon and aluminum chloride, according to the reaction

$$2Al + 3HCCl_3 \rightarrow 3C + 2AlCl_3 + 3HCl$$

Photochemical effects are excluded, of course, by inducing the reaction in a glass reaction vessel which does not transmit ultraviolet light that causes reaction without the presence of the aluminum power as absorber.

It should be emphasized at this point that, while the thermal effects of flash lamps are drastic, so also are the photochemical effects. The flash-lamp emission contains quite intense ultraviolet and blue radiation, and in many cases this can cause breakup of molecules which, offhand, one would think quite innocent. When these molecules are in the liquid phase, and even sometimes when they are in the gas phase, they frequently explode with considerable violence. Kuebler and I discovered this one day when trying to bring about a certain reaction in a series of different organic solvents. As long as the solvent did not absorb blue and ultraviolet radiation, there was no problem. But when a mixture of benzene and bromobenzene (which absorbs in this region) was flash-heated, a great photochemical detonation occurred, reducing reaction vessel and flash lamp to fine pieces. Fortunately, the reaction was carried out in a sturdy cabinet designed mainly for protection against electrical shock, so we were not injured. It should be borne in mind, however, that unless one is specifically studying photochemical reactions in this way, gases or liquids that absorb the flash radiation should be avoided.

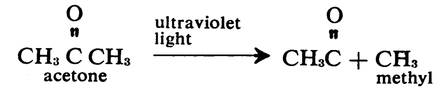
Reactions of type 5 have been achieved mainly with salts deposited on carbon fibers. Various gaseous and solid materials form in the flash, due to thermal breakdown of both absorber and coating. For example, the molecule AlCl has been detected when carbon grids coated with the salt aluminum chloride ($AlCl_3$) have been flash-heated. As mentioned above, we have not studied these reactions extensively as yet.

Application to Spectroscopy

The most recently published application of the flash-heating method has been its application to the rapid optical absorption spectroscopy of reactions started by the strong heating of solids, as devised by Kuebler and me (*6*). To discuss this, it is necessary to review first the flash photolysis and kinetic spectroscopy experiments of R. G. W. Norrish and G. Porter in England (*7*) and of G. Herzberg and D. A. Ramsay in Canada (*8*) during the past decade or so. These workers discovered that the photochemical effects of flash lamps would produce large bursts of molecules of short life, called free radicals. These molecules had been thought for several decades to be highly reactive and important intermediates in many chemical reactions. Up to this time, however, it had been very difficult to make physical measurements of the molecules because they were so highly reactive—that is, their tendency to combine with almost any other molecule at almost every encounter had always prevented formation of a high enough concentration to be measurable instrumentally, except in a very few instances.

But the photochemical effects of flash lamps were found to produce free-radical concentrations large enough to be examined physically by optical absorption spectroscopy. This is the selective removal (absorption) of visible or ultraviolet light in discrete bands or lines that are characteristic of the molecules or atoms through which a white background light is shining. (The dark Fraunhofer absorption lines in the sun's spectrum, for example, are due to atoms in the cooler outer gas layers of the sun absorbing certain wavelengths of the sun's white emission from the interior.) I shall describe this for the case of a very important free radical called methyl (CH_3), which had eluded spectroscopists and other workers in physical methods for years.

When many different organic molecules are subjected to blue or ultraviolet light, a photochemical break in the molecule can occur. An example is the photoylsis (splitting with light) of the acetone molecule, which reacts in this way:



$$\underset{\text{acetone}}{CH_3\overset{\overset{O}{\|}}{C}CH_3} \xrightarrow{\text{ultraviolet light}} CH_3\overset{\overset{O}{\|}}{C} + \underset{\text{methyl}}{CH_3}$$

Of course, as more ultraviolet light enters the reaction chamber per unit time, more methyl will be produced. When a flash lamp irradiates this reaction vessel, enough methyl is produced for its absorption spectrum to be recordable, as long as the recording is done quickly (*9*).

The technique used to record this spectrum is called flash photolysis and kinetic spectroscopy, and it is carried out with the apparatus shown schematically in Fig. 10. This consists of a transparent reaction cell, usually made of quartz, beside which is placed an intense flash lamp for preparing the

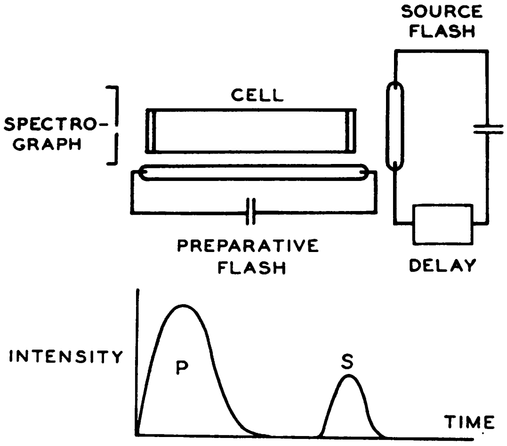


Fig. 10. (Top) Schematic diagram of flash photolysis apparatus for recording absorption spectra during rapid chemical reactions. (Bottom) Typical oscilloscope trace of light pulses from preparative flash *P* and spectroscopic source flash *S*.

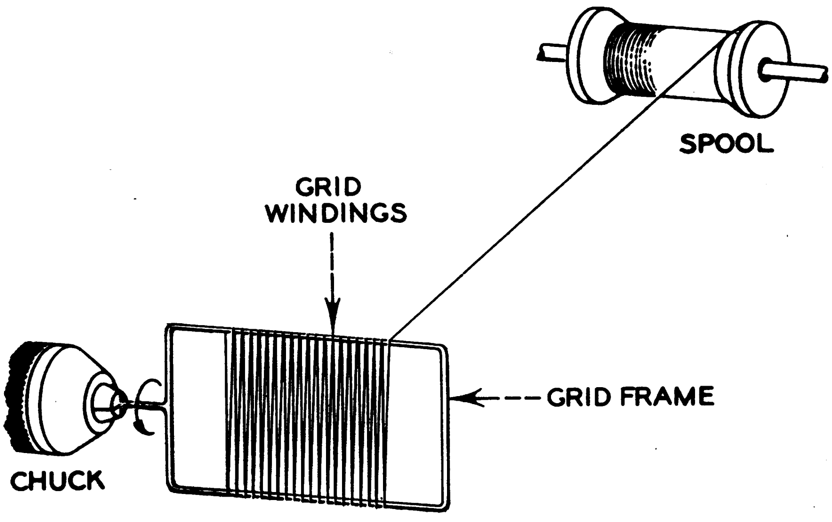
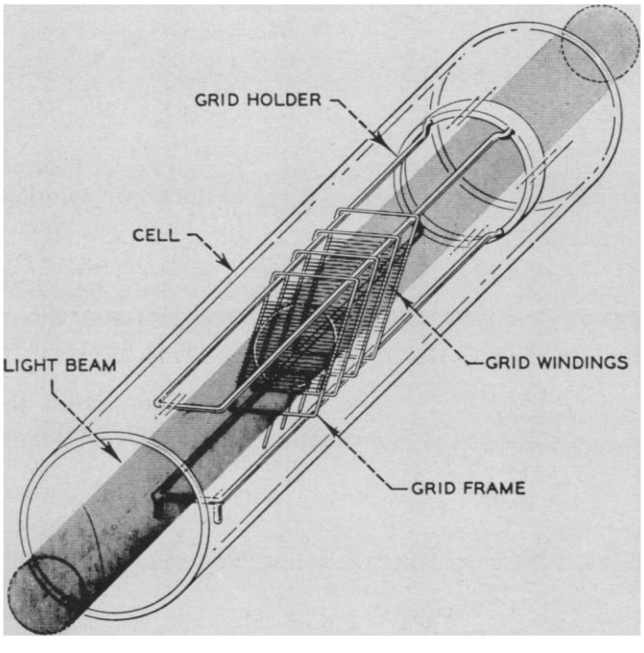


Fig. 11. Method of winding fibers on a frame for use in flash heating and kinetic spectroscopy.

free radicals. At one end of the cell is placed a second flash lamp (white background light) that is focused through the reaction zone onto the slit of a spectrograph placed at the opposite end of the cell. The second flash lamp is arranged to fire at an adjustable interval after the preparative lamp fires. By varying the delay interval properly, it is possible to perform a series of experiments that show the absorption spectrum of the molecules present at different times as the reaction proceeds. Thus, in the case we are considering, a large quantity of acetone will be broken apart to form methyl radicals when the preparative lamp fires, and we can follow the methyl absorption spectrum as the radicals are removed by reaction with other molecules in the system, including themselves. Reactions that occur in times as short as perhaps 5 microseconds can be studied in this manner.

It occurred to us that flash heating might be applied to the preparation of free radicals for kinetic spectroscopy in the same way that flash photolysis had been applied. We already had been using much the same experimental arrangement—a cell and an intense preparative flash lamp. Why not put a suspension of small solid absorbers in the cell and place a spectroscopic flash source behind the cell? Then we should be able to record the absorption spectra of thermally initiated, rather than photochemically initiated, reactions in a completely similar way.

We decided to use, as our suspension of solids, grids of either fine tungsten wire or carbon filaments, since both materials have a high melting point and can be formed into thin, sturdy cylinders, of diameter as small as 10 microns. [Small diameters cause intense heating in the flash (see Fig. 5).] In our most successful design the grids were wound on frames made of quartz rod, as shown in Fig. 11. The tungsten grids were quite easy to make, because strong tungsten wire of the proper size can be purchased commercially. The carbon grids presented more difficulty, but Kuebler found that satisfactory units



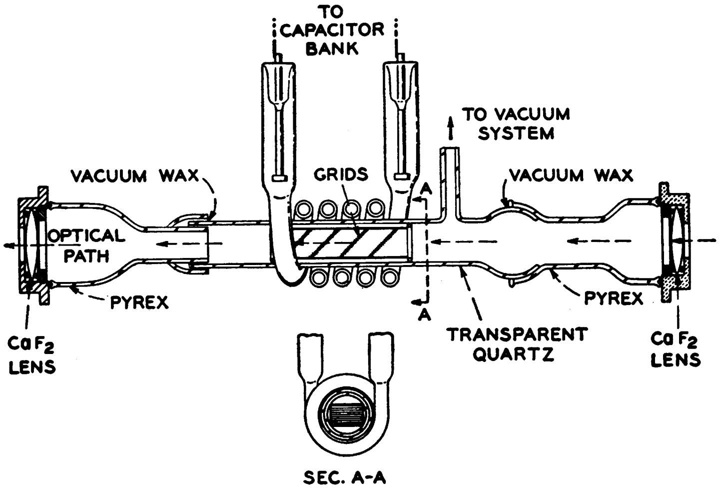


Fig. 12 (left). Cell containing grids used for flash heating and kinetic spectroscopy.

Fig. 13 (above). Cross-sectional diagram of cell for flash heating and kinetic spectroscopy, with lamp and grids in place.

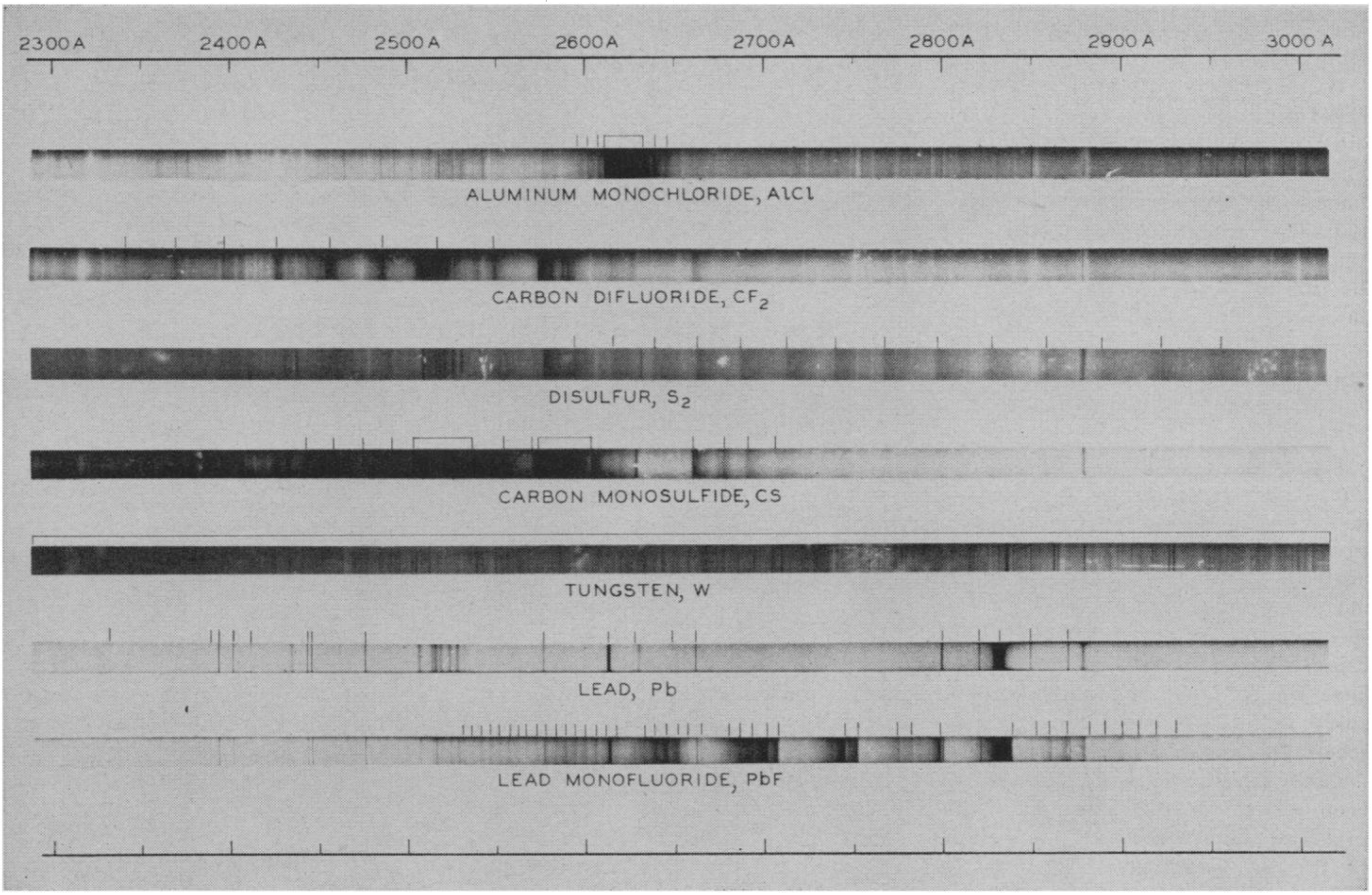


Fig. 14. Absorption spectra of thermally produced short-lived molecules, obtained by flash heating and kinetic spectroscopy.

could be made by winding monofilament rayon of 13-micron diameter onto the quartz frame and then slowly charring the fibers in a resistance furnace at 950°C overnight in a stream of nitrogen gas. A black carbonaceous fiber is formed, not unlike the carbon filaments used in early electric lamps.

Four of these grids were then racked inside the cell, as shown in Figs. 12 and 13, so that the optical path from the flash background source lamp could be focused through their centers. The fibers were fine enough so that each grid blocked only about 1 percent of the light, a blockage which did not disturb the optical system appreciably.

Now, as shown in Fig. 13, this cell was placed between a spectroscopic flash source (to the right of the cell) and a spectrograph (to the left of the cell). When the helical preparative flash (of 150-microsecond duration) fires, a cloud of thermally produced short-lived fragments of molecules forms around the grid fibers. The absorption spectra of these fragments can be recorded on film in the spectrograph after various time intervals, just as in the flash photolysis technique. A large number of short-lived molecules have been observed in this way; some of them are listed in Table 1.

This method of producing short-lived molecules for spectroscopic study has one important advantage that has not been mentioned—that photochemical effects are not needed to start these reactions. In all of the flash photolysis work carried out in the past decade, there has always been some sort of photochemical absorber present in the reaction vessel so that the reaction will start when the preparative flash fires. But sometimes this can prove to be a disadvantage, as I shall explain, taking the methyl radical as a very good example.

The methyl radical exhibits two main absorptions which can be studied by optical absorption spectroscopy. They occur in two wavelength regions: 2140 to 2160 angstroms and 1300 to 1500 angstroms (*9*). The parent molecules from which methyl can form through normal photochemical effects from flash lamps absorb light strongly in both of these regions. That is, the absorption spectra of the radical and its parent molecule overlap and interfere with each other. Now, in order to allow some of the background light to pass into the spectrograph to record a spectrum it is necessary to use a very small amount of the parent compound initially; then it must be destroyed completely with the preparative photochemical flash before the methyl spectrum can be recorded. Both factors make the methyl spectrum difficult to study by the photochemical-preparation technique.

But with flash heating, since no photochemical absorption is necessary to start the reaction, alternate thermal processes in transparent materials may be used to prepare methyl. The nonabsorbing gas methane, which cannot be photolyzed with the usual flash sources, will break down with flash heating as follows:

$$\underset{\text{methane}}{CH_4} \xrightarrow{\text{flash heating}} \underset{\text{methyl}}{CH_3} + H$$

Since the methane does not absorb light of wavelength greater than about 1200 angstroms, it does not interfere with either of the methyl absorptions at any point of the reaction.

We have obtained the higher-wavelength methyl spectrum in this way, and also the analogous spectrum of deuteromethyl (CD_3) obtained from the methane CD_4, which contains four heavy hydrogen (deuterium) atoms instead of four normal hydrogen atoms. This is the first time these radicals have been observed physically in purely thermal reactions, although they have been suggested as intermediates in such reactions for many years.

Reproductions of some of the more characteristic absorption spectra of short-lived species that we have obtained by flash heating are shown in Fig. 14. The term *short-lived* means just that—that a few milliseconds after the preparative flash, none of these spectra could have been recorded, because the molecules responsible would have reacted and changed into molecules with very different absorption spectra.

Other research groups have recently been applying flash-heating techniques in different directions. At the University of Illinois, radiochemist Kay and his co-workers are examining the reactions that occur when lead atoms form by radioactive decay of a gaseous parent material mixed with other gases, such as argon, carbon monoxide, or methane. The lead atom is formed at very high velocities—that is, at an extremely high "temperature" (many thousands of degrees). The question to be answered is what happens to the lead atom when it finally slows down enough, through collisions with other gaseous molecules or atoms, to form a stable chemical bond. Kay's experiments with lead foils evaporated by flash heating should answer at least parts of this research question.

At the U.S. Naval Radiological Defense Laboratory in San Francisco, flash lamps are being used as heat sources to study the physical changes that occur when solids are heated rapidly. The high-intensity light flash is absorbed on the front surface of a blackened slab of the solid material to be measured. At the rear surface of the solid, a fast heat sensor records the temperature changes on an oscilloscope. From a photograph of the oscilloscope trace the workers can calculate the heat capacity, thermal diffusivity, and thermal conductivity of the solid under study (see *10*).

Table 1. Species observed by flash heating and kinetic spectroscopy.

Short-lived atom or molecule	Reaction conditions
Pb	Evaporation of lead*
Au	Evaporation of gold
W	Evaporation of tungsten
SiO	Evaporation of quartz
AlCl	Evaporation of aluminum chloride from carbon grid
CS	Thermal breakdown of rayon
CS	Carbon + sulfur hexafluoride gas
S_2	Carbon + sulfur hexafluoride gas
CF	Carbon + sulfur hexafluoride gas
CF_2	Carbon + sulfur hexafluoride gas
CF_2	Carbon + carbon tetrafluoride gas
PbF	Lead + sulfur hexafluoride gas*
PbF	Lead + carbon tetrafluoride gas*
PbO	Lead + oxygen gas*
CH_3 or CD_3	Carbon + methane or carbon + deuteromethane

* Work done with J. G. Kay.

S. B. Martin and his co-workers at the same laboratory (*11*) and Kuebler and I (*12*) have studied the thermal breakdown of plastics and polymers with intense flash lamps. Gaseous products were analyzed with the gas chromatograph. More recently, groups headed by S. B. Martin at the Naval Radiological Defense Laboratory, H. Friedman at the General Electric Space Sciences Laboratory in Philadelphia, and M. Wacks at the National Bureau of Standards in Washington have experiments in advanced stages in which time-of-flight or conventional mass spectrometers are used to analyze the products of plastics, polymers, and other organic solids heated with flash lamps. The sample and the flash lamp may be placed very close to the sampling inlets of these instruments, and this allows examination of the molecular fragments very soon after the flash. Studies such as these should prove very valuable in preparing organic solids usable under conditions of strong heating, such as in rocket re-entry, and in clothing resistant to heat from an atomic or nuclear blast.

In this article we have had to glance quickly at a number of reactions that involve flash-heated solids. There are many reactions that could not be mentioned, and still more that have not been studied—almost an endless number. It is hoped that this discussion will acquaint, and perhaps intrigue, the reader with a field that seems to be bounded only by the imagination.

References and Notes

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