LASER INVESTIGATION OF SURFACE PROPERTIES OF MATERIALS

by

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I. INTRODUCTION

Since man generated and controlled coherent light by a laser in 1960, the number of different applications of lasers have been growing rapidly. Because of their coherency, intensity, directionality and monochromaticity, lasers have been used in precision measurements, in scientific instrumentation for general physics experiments such as Raman spectroscopy, plasma diagnostics, and interaction between waves and matter, in metal working, in biological and medical research and in communications, particularly in space communications. Lasers, especially gas lasers, have also been excellent devices to measure optical properties of materials such as aberration of lenses (1) and indexes of refraction (2), etc. Recently several workers--J. Renau et al (3), J. Renau et al (4), G.A. Massey (5),--have used a laser beam to study the surface properties of materials by measuring the reflectance of laser beam from the surface. The present report discusses an application of a laser beam to find an objective indication of the extent of heat damage on wheat kernels by measuring reflectance of a laser beam from their surface.

In recent years some experiments have been performed to explore optical properties of agricultural products. For example J. Palmer (6) measured the reflectance of potatoes and soil clods to differentiate between them by the difference of reflectance. D.R. Massie and K.H. Norris (7) measured the reflectance properties of grains for application in the design of infra-red grain driers. G.S. Birth (8) measured the reflectance and transmittance to find out the smut content of wheat. Other workers were interested in optical methods to sort fruits and vegetables. All of them have used conventional light sources such as tungsten lamps and mercury arcs, which are incoherent and not monochromatic. Some experimental studies with fine particles (9)(10) reported recently have revealed that there was no difference in the propagation, reflection and scattering of laser and of non-laser light beam. But we can still take advantage of their high collimation and intensity in reflection experiments. That is, the need for any external collimating or focusing optics is eliminated when we use a laser instead of a conventional light source. The He-Ne gas laser's wave length of 6328 Å was known as a reasonable wave length for distinguishing between grains in reflectance measurements. Therefore, the present experiment was performed with a He-Ne laser.

To measure the backscattering beam an integrating sphere was used in this measurement.

It is known that the reflectance of the surface of a wheat grain depends upon its roughness and spectral characteristics. Also, it may have some correlation with the extent of heat damage on wheat kernels. An experiment using a spectro-reflectometer showed that it is very difficult even to distinguish hard red winter wheat from hard red spring wheat by their spectral characteristics. Therefore it was assumed that surface roughness is the dominant factor in the reflectance measurement.

To measure the surface roughness precisely the interferometric technique should be used. This technique, however, requires a highly precise instrument and a careful technique. So reflectance was measured by means of a phototube. Two aperture sizes were tried in the present work in order to study the total reflectance and partial reflectance.

The result shows that heat damaged samples can be distinguished from sound samples by the partial reflectance method within the near field of a laser beam, depending upon the degree of damage.

II. EXPERIMENTAL ARRANGEMENT

A. Instrumentation

Figure 1 shows the arrangement of the experiments. A continuous helium-neon gas laser, the Spectra-Physics Model 122, was used as a light source. Its total output was 3.6 mW and 83% of that was emitted at 6328 Å. The beam diameter $\frac{1}{e^2}$ points is 0.7 mm. The beam was vertically polarized. The beam passed through the entrance port of the integrating sphere and illuminated the sample which was held at the opposite port. The sample holder was connected to the motor through a gear system to control the rotating speed of the sample holder. The total reflected beam from the sample was collected by the integrating sphere and detected by a photodetector mounted on the top of the integrating sphere. The output of the photodetector sensor is connected to the photometer, IL 600, and to a EAI 1130 variplotter which was used to record the output of the photometer.

a. Gas Lasers

The gas laser is one of the oscillators that can generate coherent monochromatic electromagnetic radiation at the wavelengths from the quartz ultraviolet near 2000 Å to the far infra-red at 400 microns (11). There are four kinds of lasers; gas lasers, solid state lasers, semiconductor lasers, and liquid lasers. Each of them has its own particular advantages and disadvantages. But at the present gas lasers are superior to others for almost all purposes. Most of the original experiments on mode structure, saturation, magnetic field effects, noise and

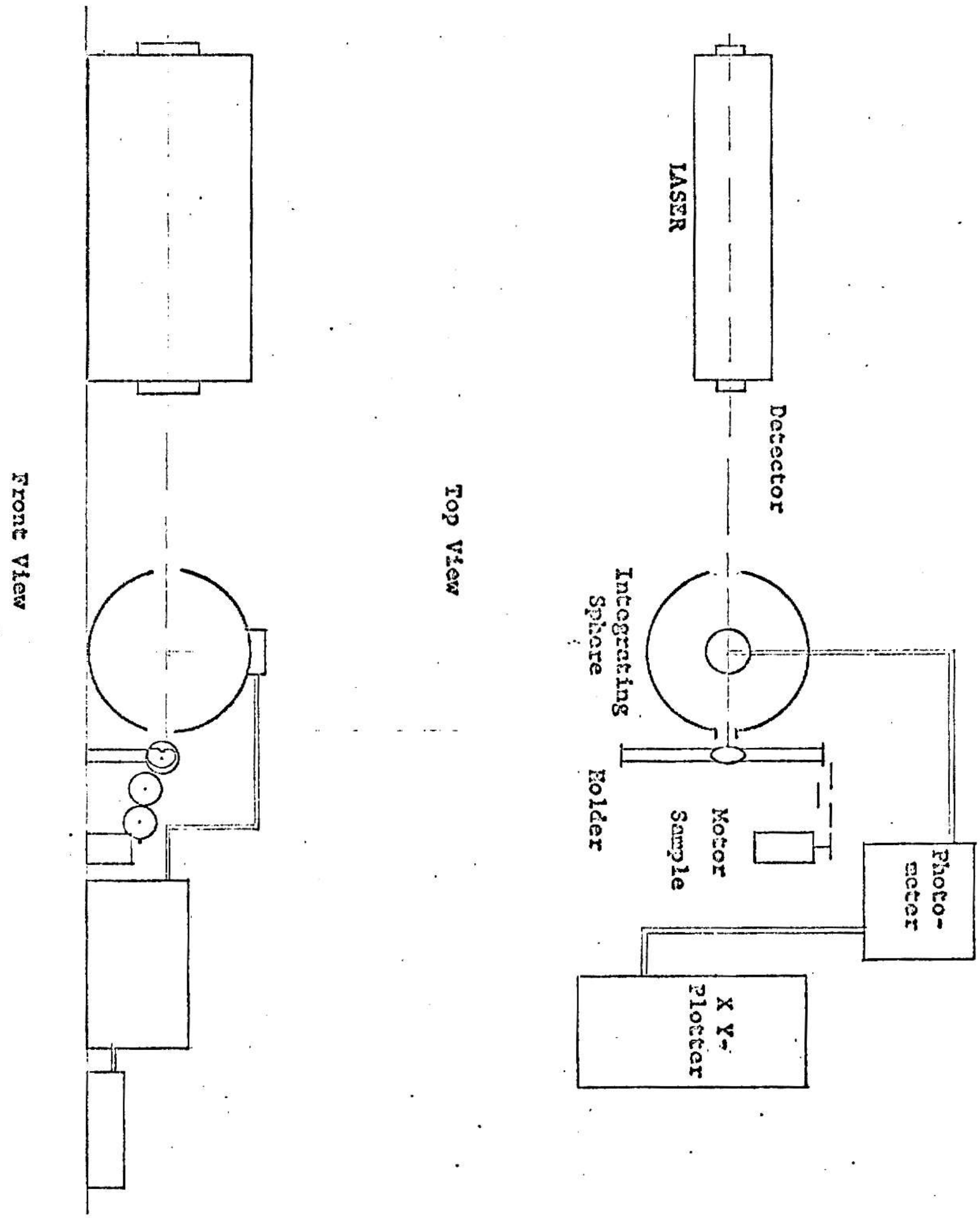

Fig. 1. Schematic Diagram of Equipment

internal modulation was done on gas lasers. Therefore gas lasers are the best known and the most commonly used in laser applications.

Gas lasers can be divided into three types according to the excitation method. At present electric discharge driven lasers are the only type available commercially; the lasers excited by optical pumping and chemical reaction are still in the experimental stage. The present section is a survey of basic mechanisms of operation and characteristics of the output beam of gas lasers that are excited by electric discharge.

1. Basic principles of gas lasers

Fundamentally, a gas laser consists of a long cylindrical tube containing the gaseous medium, two plane mirrors facing each other, and a means for exciting the discharge in the medium. Figure 2 shows the simplest form of gas laser.

At a particular absolute temperature T, a gas in the equilibrium condition has a population distribution among the various energy levels that is as follows. Let ΔE by the energy difference between level 1 and level 2 in Figure 3, then the ratio of the populations in the two levels is given by

$$\frac{P(E + \Delta E)}{P(E)} = \exp(-\Delta E/kT) \tag{1}$$

Therefore, the upper energy level has less population than the lower energy level. If a wave having an energy equal to the energy difference ΔE between the energy levels is incident upon the gas, it will be absorbed and raise some of the atoms

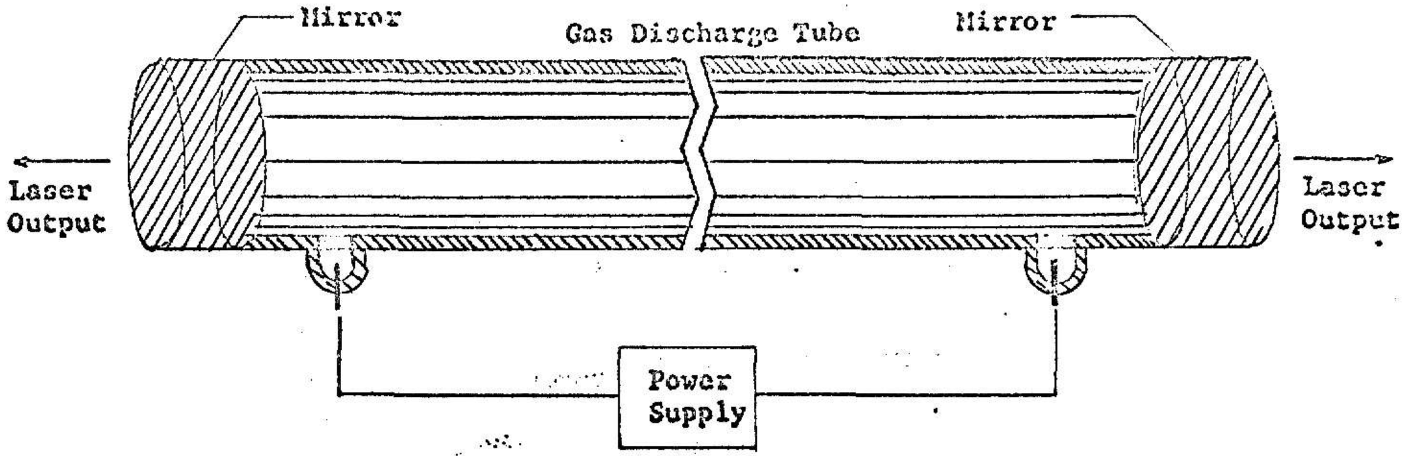

Fig. 2 Essential components of a gas laser.

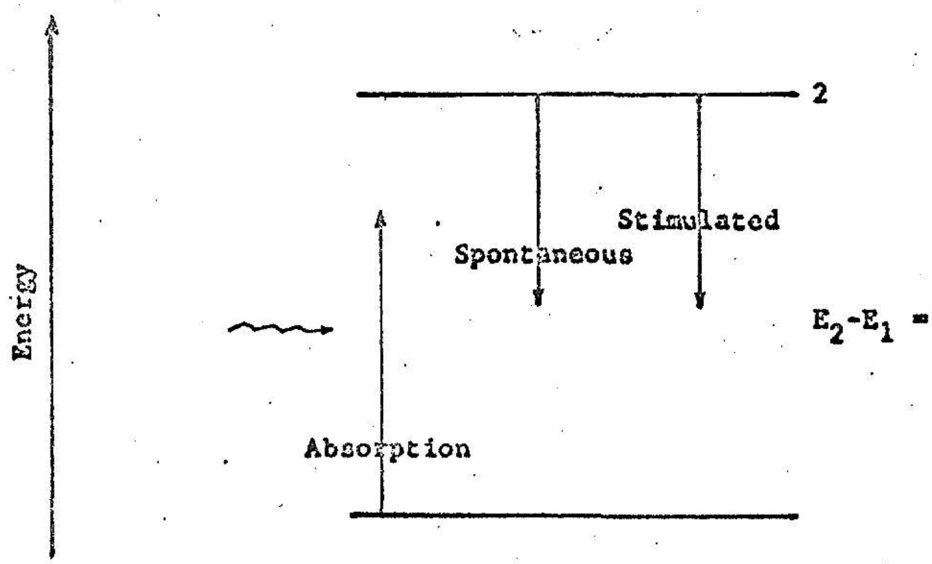

Fig. 3 Energy-level diagram of simple atomic system

in the lower state to the upper state, that is, the atoms in level 1, can absorb quanta and be excited to level 2. Then the atoms in level 2 can emit quanta by the spontaneous emission process as they return to level 1 and maintain the equilibrium condition. But under certain unusual conditions it is possible to have a situation in which the upper level has a greater population than the lower level. This situation is a population inversion. In this case atoms in level 2 can be stimulated by the incident wave to emit quanta and return to the ground state faster than they would by spontaneous emission. As a result the incident beam will be amplified. This stimulated emission is used as a source of radiation needed to excite the cavity. As in other oscillators a means of feedback is needed to sustain oscillagion. A gas laser has a pair of highly reflecting mirrors at either end of an optical path to provide the feedback.

Just as in other steady-state oscillators some sort of saturation mechanism should exist to prevent the amplified wave from being amplified infinitely. This is provided in the stimulated emission process. That is, there is a final limit determined by the rate at which the electric discharge pumps excited atoms into the upper state, which is responsible for the laser inversion itself.

As shown above a laser can be analyzed in the same terms as other electronic oscillators.

However, the resonant cavities used in gas lasers are different from those used in microwave work. There are two important differences. First, their dimensions are very large in comparison with a wave length. Secondly, the reflecting walls of laser cavities do not completely enclose the electromagnetic field. The resonant cavity consists of two rather small mirrors a large distance apart.

With this structure it is possible to select a small number of desirable electromagnetic waves from among very numerous modes of a resonant cavity large in size in comparison with the wavelength and to make the selected modes have higher Q's than the remainder. The modes of highest Q are called axial modes and the remaining modes are called off-axial modes. In order to have the difference in Q between the axial and the off-axial modes significant the mirror size should be sufficiently small. In this way, the resonant modes will be restricted to the axial modes

In other words,the quality of the laser beam can be changed by changing the geometry of the resonant cavity. Therefore the choice of cavity geometry of a laser depends upon the purpose for which it is to be used. When the single mode of operation is required the output power suffers the sacrifice and vice versa.

The thermal motion of the emitting atoms in the gas laser causes a shift in frequency of all the spectra emitted by a gas laser. Although thermal motion takes place in three dimensions, only motion parallel to the line of sight is importance in this phenomenon. This is referred to as Doppler Shift. The Doppler width of a given gas laser transition is of considerable importance in determining the laser operating characteristics. That is, the Doppler width is the most important factor in determining the gain of a gas laser and it determines the range of frequencies over which laser action takes place.

2. He-Ne gas laser

The first gas laser was a He-Ne laser and it was also the first continuous wave laser. A large number of wavelengths can be emitted by neon transition. The wavelengths from 5853 Å to 124.6 μ are available. But only three wavelengths--6328 Å, 1.15 μ and 3.39 μ--have been widely studied and used (12). In particular, 6328 Å has been most commonly used in the laser applications research. The laser of the present experiment emits also these three wavelengths. Therefore these three wavelengths will be discussed in this section.

The helium-neon gas laser emits a c.w. coherent beam with the application of an electrical discharge in a plasma tube containing a gas mixture of 1.0 mmHg of helium and 0.1 mmHg of neon. The operation of this laser can be explained with the aid of the helium-neon energy level diagram in Figure 4 (13).

The energetic electrons in the discharge excite helium atoms into a large number of excited states. Many helium atoms collect in the long-lived metastable states. Then these metastable helium atoms raise the neon atoms to upper energy levels (labeled 2S) by colliding with unexcited neon atoms and exchanging energy with them. Therefore the population inversion takes place in the neon to achieve stimulated emission. Table 1 shows the properties of the three most important neon lasers (14). The oscillation at 1.15 μ could be achieved without helium, but the gain is reduced. The oscillation at 6328 Å can not be obtained with neon alone. In this laser the 3.39 μ infra-red

Table 1. Properties of Neon-Laser Transition

Wavelength	Transition	Typical grain db/meter	Typical Power Mw
6328.2 Å	$3S_2 - 2P_4$	0.4	50 - 100
1.15 μ	$2S_2 - 2P_4$	0.4	50 - 100
3.39 μ	$3S_2 - 3P_4$	25	50 - 100

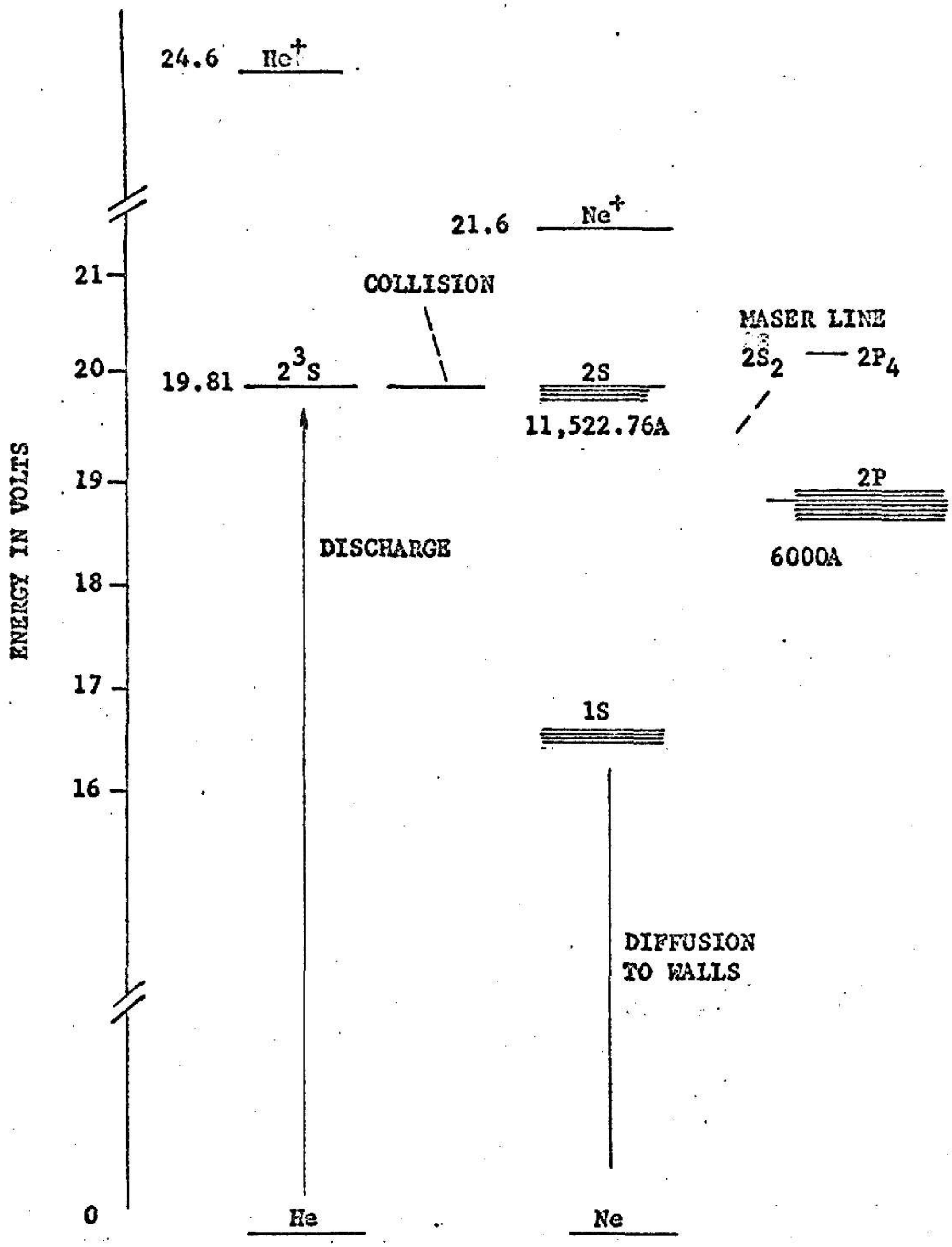

Fig. 4 Energy-level diagram for He and Ne.

wavelength is the most dominant one. Generally this transition is not useful. To avoid this wavelength an optical system which combines the functions of plane reflection and prismatic selection is used.

3. Characteristics of output beam

There are many propagating modes for a light traveling in free space. The simplest of these are gaussian modes. Gas lasers are able to product this type of wave because of their homogeneous isotropic amplifying medium and very small index of refraction. Practically, however, in a multimode operation the frequency fluctuation due to changes in geometrical length of the cavity, and the amplitude fluctuation resulting from the change of the discharge condition make the wave front different from the gaussian mode, the ideal output mode.

A feedback principle may be used to achieve amplitude stability, but this has a limitation.

The frequency stabilization of a laser system can be achieved either with respect to one of the modes of an external cavity or with respect to the atomic line itself. A temperature controlled and vibration-free environment keeps the modes of an external cavity stable. For frequency stabilization on the atomic line a discriminator can be used but it still has a restriction.

b. Integrating Sphere

The Coblentz hemisphere, the heated-cavity absolute reflectometer, and the integrating sphere are three basic instruments which could be suitable for measurement of reflectance regardless of the nature of the reflecting distribution function. The most suitable one in the visible wavelength region is the integrating sphere (15). The integrating sphere which was used in this experiment is made up of two 89-mm-diameter hemispheres which are joined together by flanges as shown in Figure 5. Because the flux incident on the detector's field of view is very much affected by the reflectance of the surface, the inside of the sphere was smoked with magnesium oxide in order to make the inside surface a very good diffuser of uniform reflectance (16).

c. Photodetectors

Photodetectors are used to convert the optical information to electrical information. The basic characteristics of these devices is the linear proportionality between the number of incident photons and the number of electric charge carriers produced.

Generally the high frequency response, noise characteristics and bandwidth are important characteristics of photodetectors, particularly when they are used in communication systems.

To improve these characteristics many kinds of photodetectors have been invented. Anderson and McMurtry (17) give an excellent status report on photodetectors.

Photodetectors can be divided into two types: Vacuum type detectors and solid state type photodetectors.

Vacuum type photodetectors include (i) a photoelectric cathode, (ii) secondary electron emitters, and (iii) photoemissive detectors such as vacuum photodiodes, photoklystrons, the traveling-wave phototube, the dynamic cross-field electron

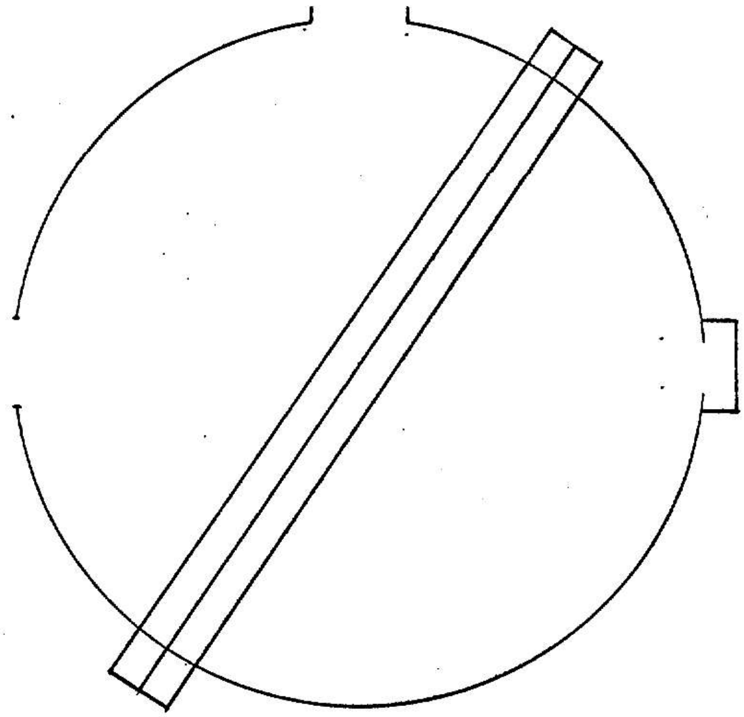

Fig. 5. The Integrating Sphere

multipliers and the static cross-field electron multipliers.

Photoelectric cathodes are quite acceptable in the visible region, but they cannot be used beyond about 1 micron. These devices have no internal gain and the sensitivity is low.

Secondary electron emitters were developed to overcome the disadvantages of the photocathodes.

Photoemissive detectors were made to improve the high frequency response of the conventional photodetectors.

Each one has its own advantage. At present the static crossed field photomultiplier is the best for base band applications and the reflection dynode multiplier traveling wave tube is the best for bandpass applications.

Solid state type photodetectors are divided into two categories. The first type is depletion layer photodetectors which consist of junction photodiodes, point contact photodiodes and surface-barrier photodiodes.

It is the principle of these devices that electron-hole pairs produced around semiconductor p-n junctions by the irradiating beam can be separated by the electric field, resulting in current flow in the external circuit. Therefore any reverse-biased p-n junction can be useful as a photodetector.

The point contact photodiodes use a point contact geometry instead of a junction and the surface-barrier photodetectors use a metal-semiconductor junction instead of a p-n junction.

The other kind of solid state photodetector is one with current gain. It has many varieties. At present the avalanche diodes show the best sensitivity in most applications.

d. Recorder

Oscilloscopes and XY Recorders such as the EAI 1130 Variplotter can be used as recorders. In this experiment the EAI 1130 Variplotter was used to record the output of the photometer. The X-axis time base circuit which was included in this plotter was used.

B. Sample description

Soft white western wheat, and triump were used in this experiment to measure the reflectance. Triump were not given any treatment to compare with controlled soft white western wheat.

The soft white western wheat was treated as described as follows. In order to investigate the relation between the reflectance and the degree of the heat damage, the soft white western wheat was treated as it is described below.

Sample	Treatment
67-6005 control	No Treatment.
67-6005 A	Air dried, fan 7 hr.
67-6005 B	Heated to 60°C, 2 hr.
67-6005 C	Soaked 2 hr. heated 4 hr. at 60°C
67-6005 D	Soaked 2 hr. heated 4 hr. at 80°C
67-6005 E	Soaked 12 hr. heated 6 hr. at 80°C

It is known that a drying temperature above 71°C makes the quality of wheat lower. Therefore it can be said that sample #D and Sample #E are severely damaged (18).

C. Procedure for the experiment

A magnesium carbonate chip was used as a standard target in order to calibrate the system. This target was illuminated in the direction normal to its surface by the laser beam.

The intensity of reflectance of the beam was measured photoelectrically and the photometer was set at full scale by changing the sensitivity. At the same time the y-axis of the recorder was calibrated to full scale position, that is, 100%.

The magnesium carbonate standard sample was then replaced by a wheat sample so that the beam illuminated a spot around the crease of the wheat sample and the germ side end of the wheat oriented to the left of the beam as shown in Figure 6.

Rotation around the long axis of the wheat was produced by the driving motor which was synchronized with the x-axis motor of the recorder. The reflectance of the wheat sample was recorded as a percentage of that of magnesium carbonate sample.

The results are plotted with rotation angle as the abscissa and the percent reflectance as the ordinate. As a result, the laser beam reflectance along the circumference of the wheat kernal cross section was obtained.

The same procedure was then repeated with other samples. Figure 7 is typical example of the curves that were obtained.

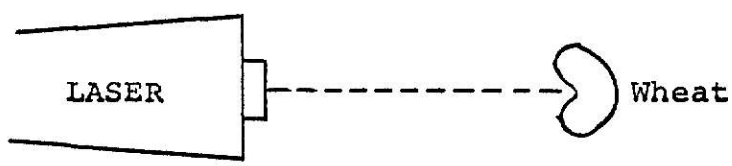

Fig. 6. A wheat sample illuminated by laser beam

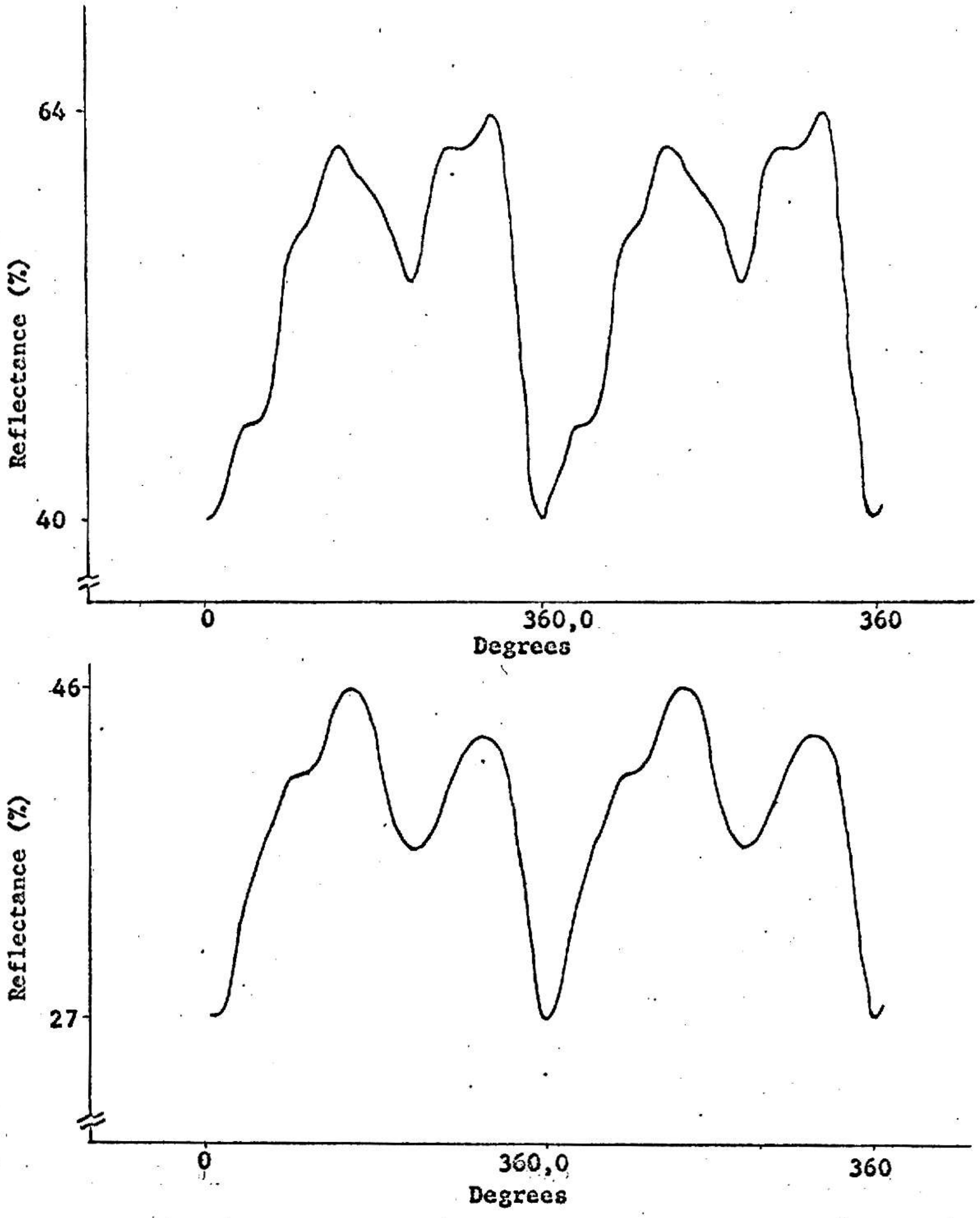

Figure 7. Examples of the Reflectance Curves

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Partial Reflectance Measurement.

The partial reflectance data were taken with a small aperture in the near field of the laser. The experimental parameters were as follows:

laser side aperture diameter	3.2 mm
sample side aperture diameter	4 mm
distance between laser and sphere	10 mm
distance between laser and sample	191 mm
diameter of the sphere	89 mm
diameter of the detector port	8 mm

Three sample classes of 67-6005 wheat kernels and sound triump wheat kernels were tested. Each class contained 20 kernels.

Examination and comparison of curves for individual samples shows that the maximum values of percent reflectance exhibit a significant spread between the 67-6005 controlled samples and the sound triump samples. The comparison of minimum values shows the same result. Table 2 shows the data.

The comparison of the maximum values of the 67-6005 controlled samples and heat damaged samples (Sample #D and Sample #E) shows a distinct difference between the controlled samples and the sample #E, and between sample #D and sample #E. But there is little difference between controlled samples and sample #D.

The experimental data justifying the above statement are

Table 2. Reflectance data of 67-6005 controlled samples and triumph controlled samples

Sample No.	67-6005 controlled sample		triumph controlled sample	
	Maximum	Minimum	Maximum reflectance	Minimum reflectance
1	33%	13%	20%	6.5
2	33	12.5	16.5	6
3	36.5	17	17.5	6.5
4	44	14.5	25	8
5	38	14.5	19	5.5
6	26.5	10.5	15	7
7	31	13.5	15	5.5
8	22.5	10	16	5.5
9	26	10	19.5	5.5
10	29	14	16	7
11	22	9.5	16.5	6.5
12	33.5	17.5	15.5	7
13	45	16.5	18	6.5
14	40	13	15	7
15	34	16.5	14.5	6.5
16	40.5	18	22	6.5
17	32.5	11.5	15.5	5.5
18	37	19	17	7
19	38	18		
20	28	14.5		

Table 3. Reflectance data of 67-6005

Sample No.	67-6005 control		67-6005 D		67-6005 E	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1	33	13	37.5	14.5	49.5	25
2	33	12.5	31	14.5	43	20
3	36.5	17	32.5	11	39.5	16
4	44	14.5	32.5	15	34.5	21.5
5	38	14.5	34.5	12.5	43	21.5
6	26.5	10.5	38	18	38	22.5
7	31	13.5	36	17	40	23.5
8	22.5	10	40	14.5	35	25.5
9	26	10	36	15	33	18.5
10	29	14	30	13.5	35	18.5
11	22	9.5	36	16	31	18
12	33.5	17.5	38	14.5	45	23
13	45	16.5	38	14	40	23
14	40	13	41.5	14	40	23
15	34	16.5	38	16	45	26
16	40.5	18	38.5	13.5	41	27
17	32.5	11.5	41	20	49.5	27.5
18	37	19	31	15.5	52	25
19	38	18	31	13	45.5	23
20	28	14.5	28	15	40.5	21

tabulated in Table 3.

To confirm the above statement statistical tests of comparison were performed, assuming each group of data comes from normal distributions with the same variance.

The "t" distribution furnishes a test of the hypothesis.

H_o: $(\mu_1 = \mu_2)$ against the alternate hypothesis

H_a: $(\mu_1 = \mu_2)$

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{S_{\bar{x}_1 - \bar{x}_2}}$$

where μ_1 and μ_2 are population means of group 1, and group 2, $\bar{x}_1$ and $\bar{x}_2$ are sample means of group 1 and group 2 respectively and $S_{\bar{x}_1 - \bar{x}_2}$ is the sample standard error of difference between the means. $S_{\bar{x}_1 - \bar{x}_2}$ is calculated by

$$S_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{\sum x_1^2 + \sum x_2^2}{n(n - 1)}}$$

where n is the number of observations in each group, and $\sum x_1^2$, and $\sum x_2^2$ are the sums of squares of group 1 and 2 respectably. The sum of squares are calculated by

$$\sum x^2 = \sum X^2 - \frac{(\sum X)^2}{n}$$

First the maximum reflectances of 67-6005 controlled samples were compared with those of 67-6005 D samples by calculating the value of "t".

$\bar{x}_1 = 35.45$ (sample D)

$\bar{x}_2 = 33.5$ (controlled)

$\sum x_1^2 = 291.45$

$\sum x_2^2 = 812.5$

$$S^2_{\bar{x}_1 - \bar{x}_2} = \frac{812.5 + 291.45}{20(20 - 1)} = 2.91$$

$S\bar{x}_1 - \bar{x}_2 = 1.704$

Therefore

$$t = \frac{35.45 - 33.5}{1.704} = 1.144$$

This value of t is in the region of acceptance with the probability of a type I error, α, 0.05. Hence the null hypothesis, $H_o; \mu_1 = \mu_2$ is accepted.

Therefore it is not possible to distinguish the sound wheat kernel from the sample #D by this experimental method.

Comparing the maximum reflectances of sample E to 67-6005 controlled sample by the same statistical test

$\bar{x}_1 = 41.0$ (sample E)

$\bar{x}_2 = 33.5$ (controlled)

$S_{\bar{x}_1 - \bar{x}_2} = 1.9406$

$$t = \frac{41.0 - 33.5}{1.9406} = 3.865$$

With $\alpha = 0.05$, the null hypothesis, H_o; $\mu_1 = \mu_2$ is rejected in favor to the alternate hypothesis H_a; $\mu_1 > \mu_2$.

Therefore sample E can be distinguished from the controlled sample by this experimental method.

The same statistic test shows that this experiment works to differentiate sample D from sample E.

The result of similar tests for minimum values are shown in Table 4.

The result of comparison of maximum values of the reflectance are the same as the result of comparison minimum values of the reflectance. Every wheat sample gives the minimum reflectance at the crease of the wheat and the maximum reflectance at about 320° or 150° away from the crease. Therefore, measuring minimum values is more convenient.

Because of the irregularities on the inside of the bore, the exit aperture of the laser and two apertures on the integrating sphere, a small percent of the light was diffracted off the principal optic axis. This perturbs the intensity distribution of the light in the near field. As distance from the laser is increased, the diffracted light spreads away from the main beam and in the far field the intensity distribution becomes smooth (19). Hence measuring the reflectance in the far field of laser gives more accurate information than that in the near field.

In the present experiment the reflectances of 20 samples of one group were measured after 20 samples of other group were tested.

It took about 5 hours to complete the measurement of 20

Table 4. Results of "t" test for minimum values

control VS. #D	(sample #D) $\bar{x}_1 = 14.85$ (controlled) $\bar{x}_2 = 14.175$	$S_{\bar{x}_1 - \bar{x}_2} = 0.794$ t = 0.85
control VS. #E	(sample #E) $\bar{x}_1 = 22.45$ (controlled) $\bar{x}_2 = 14.175$	$S_{\bar{x}_1 - \bar{x}_2} = 0.9625$ t = 8.6
#D VS. #E	(sample #E) $\bar{x}_1 = 22.45$ (sample #D) $\bar{x}_2 = 14.85$	$S_{\bar{x}_1 - \bar{x}_2} = 0.826$ t = 9.2

samples.

The amplitude of the laser may be unstable in a long term operation such as this. Therefore, measuring one kernel from each group after other one from each group and so on would be more desirable.

B. Total Reflectance Measurement

The above discussion reveals that the experiments performed in the far field of the laser will give more accurate information. But it was not possible to perform the same experiment in the far field of the laser because the sensitivity of the system was not enough to detect the change of reflectance when the distance from the laser to samples was about 70 cm.

To increase the sensitivity the diameter of the sample side apeture was enlarged and the total reflectance data were taken in the far field of the laser.

The experimental parameters were changed as follows.

distance between laser and sphere	670 mm
distance between laser and sample	762 mm
diameter of sample side aperture	6.4 mm

other parameters were same as those of the first experiment

With the large sample side aperture a part of laser beam was reflected from the sample holder. To eliminate this undesired reflected beam the aperture was modified. Figure 8 shows the dimensions of the modified aperture.

Five sample classes of 67—6005 wheat kernels were tested using this experimental arrangement. Each class contained 20

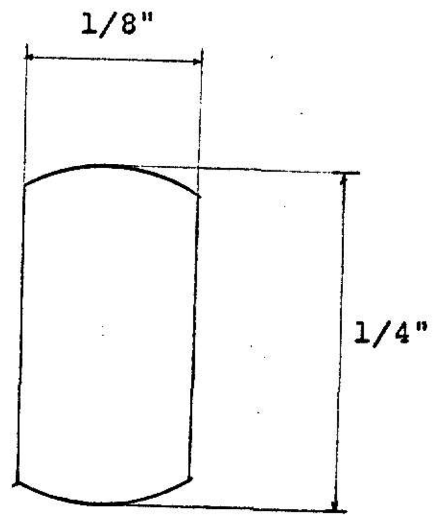

Fig. 8. Modified sample side aperture

kernels. Table 5 shows the minimum reflectance of each kernel.

The results of the test indicate that sound wheat kernels can not be distinguished from damaged wheat kernels except for example C.

According to the result of the partial reflectance measurement the result of this experiment should appear as follows:

$$\bar{x}_{CO} < \bar{x}_A < \bar{x}_C < \bar{x}_D < \bar{x}_E$$

Therefore if #C samples can be distinguished from sound samples by this method, #D and #E samples should have been distinguished from sound samples. Hence this method does not work.

The maximum values of the same experiment were tabulated in Table 7 and the summary of the statistical test was shown in Table 8.

The test reveals that there are significant differences among maximum value data of each group. The total reflectance of the first five samples of each group are too small. It was because of some mistake of equipment such as a poor gounding. But for comparison purpose, it does not make any difference.

The total reflectance method can not differentiate sound wheat from heat damaged wheat.

Table 5. The minimum values of reflectance in the far field

sample No.	67-6005 controlled	67-6005 #A	67-6005 #C	67-6005 #D	67-6005 #E
1	26.5	30	26	23.5	25
2	23.5	24	31	25	26
3	28	29	35.5	24	23.5
4	21	23	31	27.5	27
5	22	24.5	24.5	28.5	22
6	31	29	44	45	47
7	36	43.5	44	43	29.5
8	44	45	41	42	40
9	40	36	45	42	38.5
10	47	37	41	47	42
11	38	37	43	44	36
12	36	41	44	36	44
13	45	44	43	39.5	33.5
14	38.5	38.5	37	36	44
15	41	38	44	42	40
16	35.5	42.5	40.5	40.5	39.5
17	43	32	45	35	45
18	38	39	45	39	43.5
19	35.5	31	42	40	42
20	42	37	42	44.5	39.5

Table 6. Summary of the statistical test for minimum value

controlled Vs. #A	$\bar{x}_{co} = 35.575$ $\bar{x}_A = 35.05$	$S_{\bar{x}_{co}-\bar{x}_A} = 2.3241$ $t = 0.226$	$\mu_{co}=\mu_A$
controlled Vs. #C	$\bar{x}_{co} = 35.575$ $\bar{x}_C = 39.1425$	$S_{\bar{x}_C-\bar{x}_{co}} = 2.264$ $t = 1.7005$	$\mu_{co}<\mu_C$
controlled Vs. #D	$\bar{x}_{co} = 35.575$ $\bar{x}_D = 37.2$	$S_{\bar{x}_D-\bar{x}_{co}} = 5.879$ $t = 0.6702$	$\mu_{co}=\mu_D$
controlled Vs. #E	$\bar{x}_{co} = 35.575$ $\bar{x}_E = 36.375$	$S_{\bar{x}_E-\bar{x}_{co}} = 2.503$ $t = 0.319$	$\mu_{co}=\mu_E$

Table 7. The maximum values of reflectance in the far field

sample No.	67-6005 controlled	67-6005 #A	67-6005 #C	67-6005 #D	67-6005 #E
1	46	47	43	42	42
2	42	42	47	46	45
3	37	42	45	41	43.5
4	35.5	37	44	44	42.5
5	30	43.5	34.5	46	42
9	64	59	69	69	64
10	62	63	61	67	67
11	64.5	61	69	66	63
12	58	66	64	63.5	67
13	63.5	63	65	66	59
14	60	60	66	68	63.5
15	70	69	72	73	67
16	57	60	68	61	62
17	63	58	77	59	65
18	65	59	67	62.5	63
19	60	43	66	63	66
20	60	62	62	67	67

Table 8. Summary of the statistical test for maximum values

controlled vs. #A	$\bar{x}_{co} = 55.5$ $\bar{x}_A = 54.97$	$S_{\bar{x}_{co}-\bar{x}_A} = 3.8212$ $t = 0.047$	$\mu_{co} = \mu_A$
controlled vs. #C	$\bar{x}_{co} = 55.15$ $\bar{x}_C = 59.97$	$S_{\bar{x}_C-\bar{x}_{co}} = 4.1849$ $t = 1.1518$	$\mu_{co} = \mu_C$
controlled vs. #D	$\bar{x}_{co} = 55.15$ $\bar{x}_D = 58.15$	$S_{\bar{x}_D-\bar{x}_{co}} = 3.8586$ $t = 0.7775$	$\mu_{co} = \mu_D$
controlled vs. #E	$\bar{x}_{co} = 55.15$ $\bar{x}_E = 59.095$	$S_{\bar{x}_E-\bar{x}_{co}} = 3.92$ $t = 1.0064$	$\mu_{co} = \mu_E$

IV. CONCLUSION

Summarizing the analysis of the data of this experiment, the following conclusion may be drawn.

1). Every wheat sample gives the minimum reflectance at the crease of the wheat and the maximum reflectance at about 150° or 320° apart from the crease.

2). The partial reflectance measurement is a more reasonable method than the total reflectance measurement.

3). The results of the partial reflectance measurement in the near field shows that

$$\bar{x}_1 > \bar{x}_2 > \bar{x}_3$$

where $\bar{x}_1$: the average of the minimum reflectance values of sample E.

$\bar{x}_2$: the average of the minimum reflectance values of sample D

$\bar{x}_3$: the average of the minimum reflectance values of controlled sample.

V. RECOMMENDATION FOR FUTURE WORK

1). Reflectance of the surface of an opaque body depends on its microscopic configuration (20). Therefore in order to find the relation between reflectance and surface characteristic, the statistical properties of such surface must be measured (3, 16).

A stylus instrument, a modified interferometer or a scanning electron microscope could be used to measure the r.m.s. surface height, and r.m.s. surface slope.

2). To measure the partial reflectance in the far field a higher sensitivity is needed. To achieve this with the minimum noise, a chopper amplifier could be used.

3). In this experiment, the amplitude stability of the laser output is critically important. To make certain that the intensity of the incident beam remains constant, a power meter should be used to monitor the source.

4). The performance of the integrating sphere is one of importance factors in determining the accuracy of the measurement. The magnesium oxide coating is so delicate that human breath and cigarette smoke will sharply reduce the reflectivity of the surface. A sodium chloride coating would give better results (16).

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LASER INVESTIGATION OF SURFACE
PROPERTIES OF MATERIALS

by

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B. S., Seoul National University, 1962

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

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MASTER OF SCIENCE

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An application of a laser beam to detect the extent of heat damage on wheat kernels by measuring reflectance from their surface is the purpose of this report.

The equipment included (1) helium-neon laser as a source, (2) an integrating sphere coated with Magnesium dioxide, (3) a photodetector, (4) a photometer, and (5) an x - y plotter.

The partial reflectance was measured in the near field, and the total reflectance was measured in the far field. Sound wheat kernels could be distinguished from severely heat damaged kernels by taking partial reflectance data and comparing maximum or minimum values.