THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Nuclear Engineering

Final Report

NEUTRON OPTICS

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A. REVIEW OF PROJECT AND PROJECT PROGRESS

1. CONCEPTION OF THE PROJECT

This is the third and final progress report on "Neutron Optics" an experimental project sponsored by the National Science Foundation under Grant No. G-12147, effective May 1, 1960, to April 30, 1963. The project has been completely oriented toward the design and operation of a triple axis crystal spectrometer for use in the study of inelastic scattering of thermal neutrons on gas, liquid, and solid targets.

The primary objective of the experimental program has been the study of molecular motions in the liquid state. Considerable effort in this area has been expended since about 1957 at Chalk River, Ontario, Brookhaven National Laboratory, the Phillips Petroleum Company at Idaho Falls, and in England. Our own project was begun in parallel with a mechanical "phased rotor" spectrometer project, sponsored by the AEC, within our own department. In a sense these two programs have been in competition. Both are currently entering the data taking stage and it appears that a significant advantage is emerging from cross-comparison of results from the same targets.

2. DEVELOPMENT AND OPERATION OF MODEL I CRYSTAL SPECTROMETER

From the project's inception, it has been recognized that the low thermal neutron intensity and high fast neutron background from a conventional 1 MW swimming pool reactor (The University of Michigan Ford Nuclear Reactor) raises a serious question as to the practicality of competing in the neutron scattering field. As a consequence, the foremost design problem has always been to obtain counting rates high enough to allow practical experiments to be run.

As described in Progress Report 03671-1-P, the initial design was patterned closely after the spectrometer built by B. Brockhouse at Chalk River. The first spectrometer is shown in Figures 1 and 2. This design allows for "constant Q" measurements and, of course, double energy analysis. Variable angle collimators and copper monochromating crystals were used. Preliminary intensity calculations for the peak reactor energy range (0.05 eV for our system), predicted counting rates at the elastic peak of typical targets of about 10 to 20 counts per minute, a background count of about 2 counts per minute, and an energy resolution (full width at half maximum, FWHM) of about 7.5%. These conditions were believed to be just barely adequate for scattering measurements.

Initial measurements and calibrations were begun in April, 1961. It was found that the total peak count rate at 0.05 eV was 7 counts per minute with

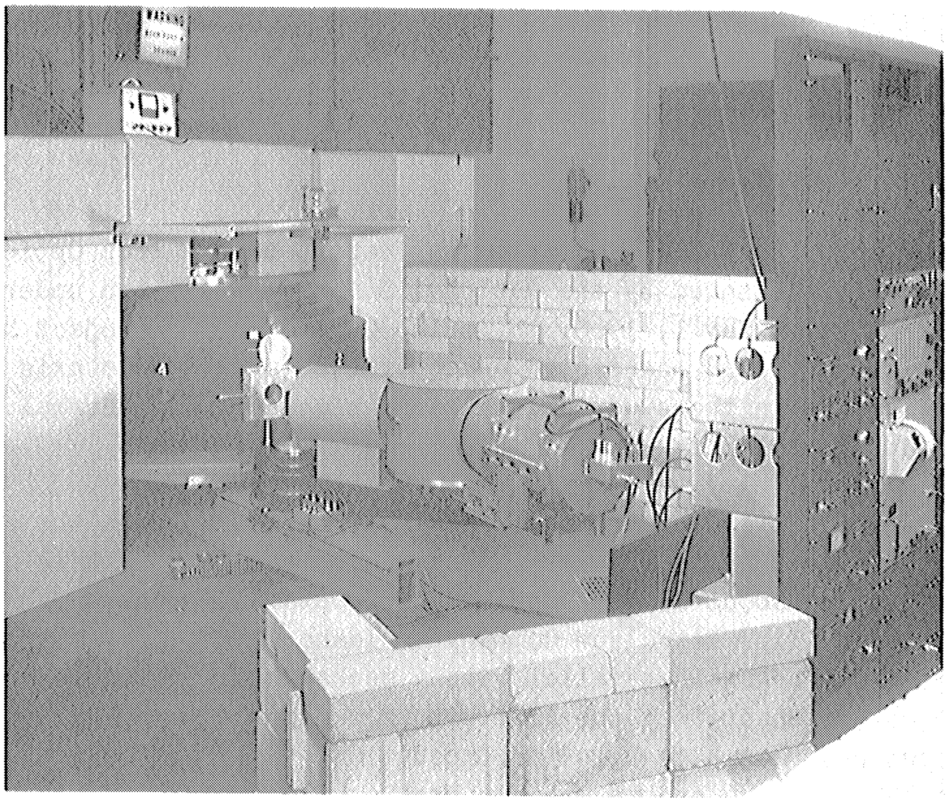

Figure 1. Model I triple axis spectrometer.

Figure 2. Model I triple axis spectrometer.

a resolution of 5.4% FWHM. The background for the system as shown in Figure 2 was higher than acceptable. By designing a temporary traveling platform to provide additional shielding housing around the second arm and detector, the background was reduced to about 0.9 counts per minute. With these conditions calibration and spectrum measurements were performed and a "high resolution" scattering experiment attempted on light water. The approximate time schedule is given in Table I.

TABLE I

TIME SCHEDULE

May, 1960 - April, 1961	Initial design, construction, procurement.
May, 1961 - February, 1962	Installation, alignment of port plug; installation, alignment of spectrometer; intensity measurements on C_nH_{2n}; resolution measurements by vanadium scattering.
March, 1962 - June, 1962	Port neutron spectrum measurements; additional (moving) shielding installed; automatic programming drives installed.
July, 1962 - January, 1963	"High resolution" scattering experiment on H_2O target.
February, 1963 - May, 1963	Spectrometer and port redesign.

The experimental results on H_2O were incorporated in a paper given at the American Physical Society meeting January 23, 1963, entitled "Structure in the Neutron Elastic-Scattering Peak in H_2O." The data and theoretical model are shown in Figures 3 and 4. Clearly, the statistics were marginal in this work, although the similarity of structure with that of the model appears more than coincidental.

3. SPECTROMETER FEASIBILITY IN RETROSPECT

The kind of statistics and time required to take the water data shown above indicated the impracticability of continuing the program with the spectrometer as it stood at the end of 1962. Of course, the principle problem was and is the reactor source intensity, but our inability to live with that intensity can perhaps be itemized in retrospect:

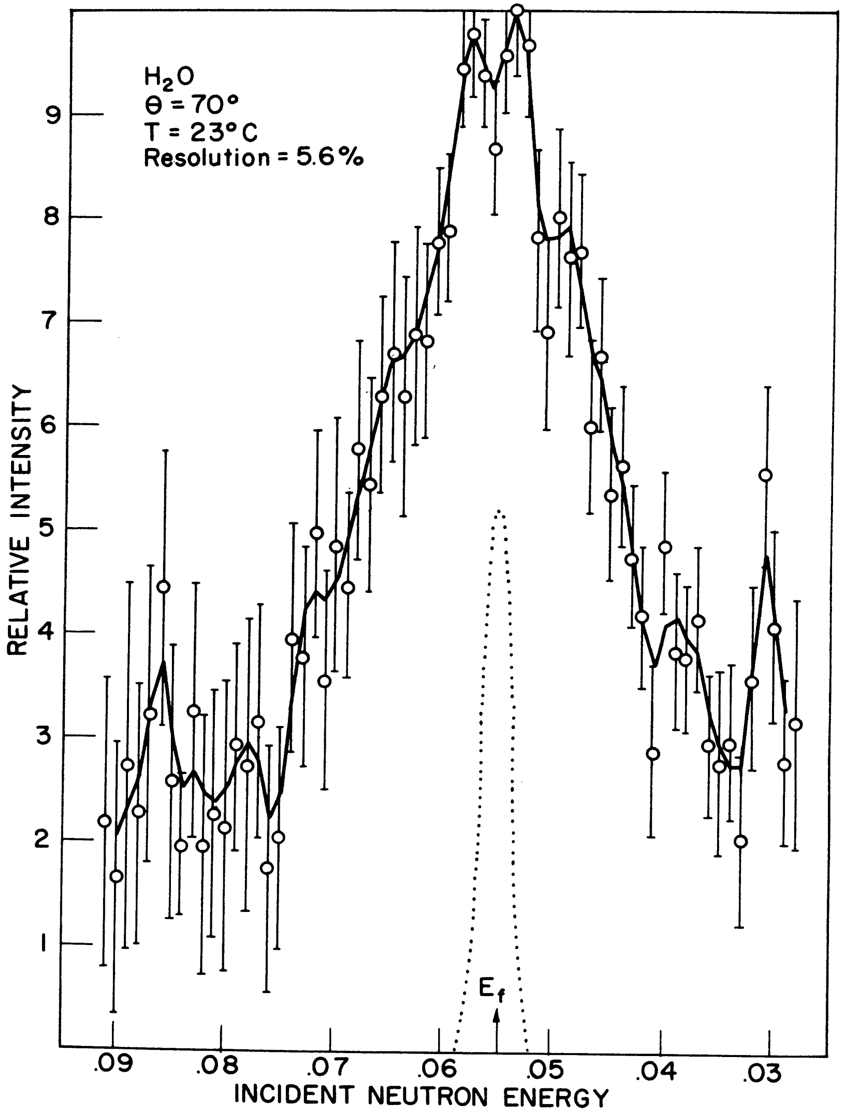

Figure 3. Neutron scattering intensity from H_2O.

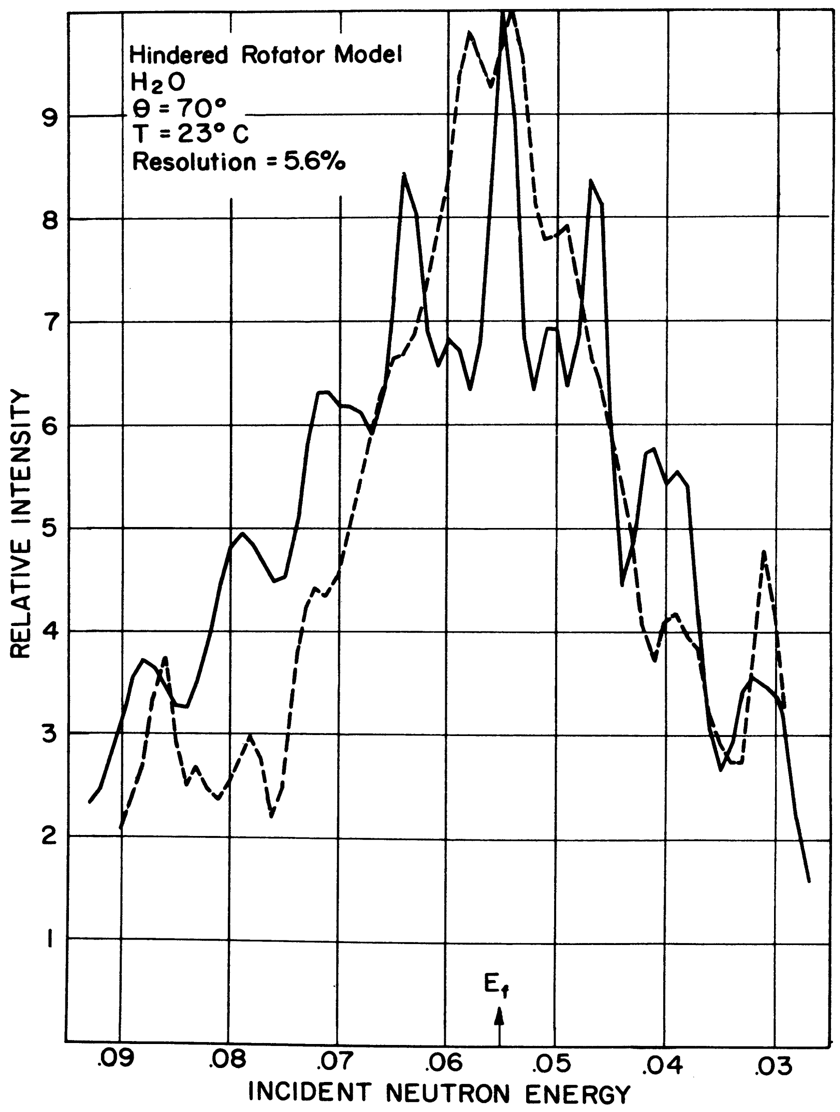

Figure 4. Comparison of scattering data and a theoretical model for H_2O.

a. The copper monochromating crystals were found to have a mosaic spread of about half that anticipated from the literature. As a consequence, the crystals and collimation were not matched for optimum intensity.*

b. Primary collimation did not take advantage of vertical beam focusing. The first collimator was purposely made adjustable in the Bragg plane, to vary resolution. However, this sacrificed vertical focusing to a large extent, because the vertical collimation walls were parallel instead of converging. Also, no vertical focusing by the crystals was attempted.

c. The solid angle subtended by the analyzing system was too small, i.e., the only limitation on useful solid angle is the investment needed in additional analyzing crystals and detector channels. Multiple detection channels are feasible.

d. The cantilevered mechanical design originally used did not permit sufficiently heavy loading of shielding material in the detector channel, and of course, would not have permitted a multiple analyzing system. Independent railroad track support for the entire analyzing system is desirable.

e. With signal to noise ratio of the order of 1 and total counting rates of only 2 CPM and lower, small system drifts, such as monitor temperature coefficients, detector inherent noise levels, reactor power shifts, produced serious fluctuation in the count rate over long periods of time. Reproducibility of data was severely handicapped by the long data taking intervals.

4. DESIGN OF MODEL II CRYSTAL SPECTROMETER

A major redesign study was undertaken in January, 1963, continuing through the termination date April 30, 1963. All of the faults listed above were attacked in an extreme effort to raise the counting intensity even at a sacrifice in resolution. (The installation of changes and calibration measurements were subsequently conducted under the new spectrometer contract (NSF GP-1032), effective March, 1963, to November, 1963). Figure 5 shows the new design installed. Visible are the much augmented shielding components, which rotate with the main Bragg arm. Measurements of the comparative intensities between Models I and II at various stages of the spectrometer are listed in Table II.

Clearly, a very large intensity improvement has been effected, although the resolution is significantly lower and the background is considerably worse.

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*As a result the resolution was considerably better than anticipated, better in fact, than all other spectrometers then in use. It was hoped to capitalize on this by examining H_2O scattering, where such resolution (~5%) would be required to reveal structure suggested by the theoretical model and heretofore not seen at high (0.05 eV) energy.

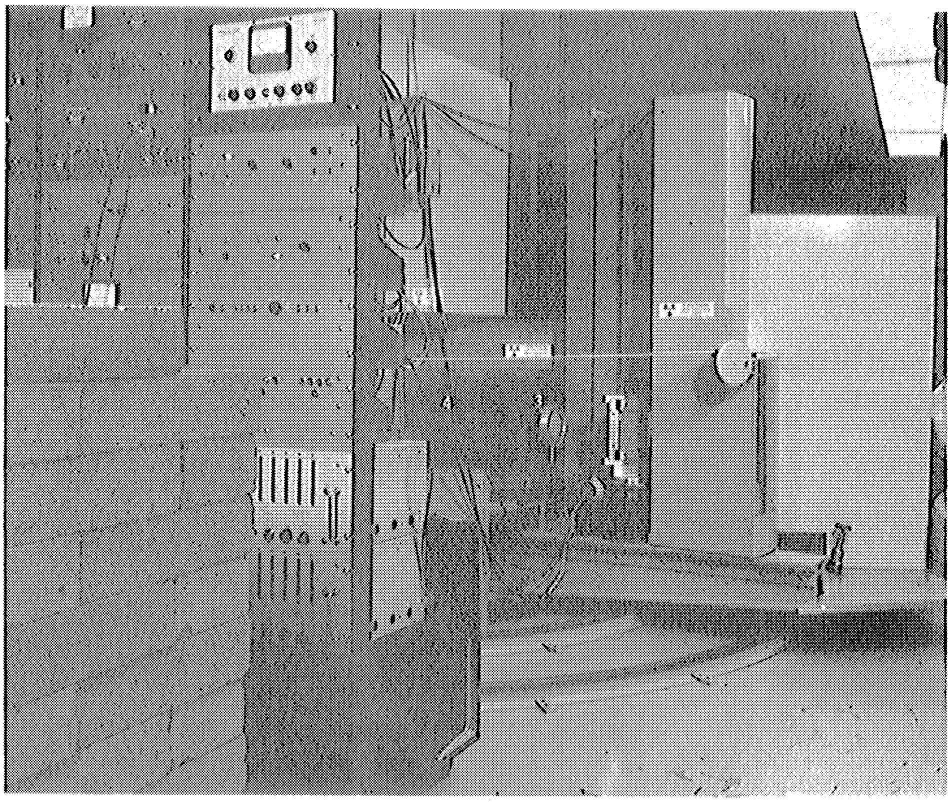

Figure 5. Model II triple axis spectrometer.

TABLE II

MEASURED INTENSITY IMPROVEMENT AND RESOLUTION LOSS

	Model I (1962) 1 MW	Model II (1963) 2 MW
A. Intensity improvement factors:		
1. Higher reactor power source level		2.0
2. Primary collimator vertical focusing and increased vertical aperture		4.0
3. Primary crystal vertical focusing (using two crystals)		1.7
4. Crystals surface treatment		2.5
5. Increased analyzer-detector apertures (using 3-in. diam BF_3 detector)		1.8
6. Simultaneous (3) analyzer-detector stations		2.8
B. Total intensity ratio		180.0
C. Total count rate (V peak at 0.05 eV)	7 CPM	1260 CPM
D. Background count rate CPM (0.05 eV)	0.9 CPM	20 CPM
E. Total signal to background ratio	8	63
F. Resolution, FWHM at 0.05 eV	5.4%	7.8%

Nevertheless, it seems fair to say that Model II does make the scattering program feasible from a statistics viewpoint. Small system instabilities do not introduce serious effects. Typical scattering spectrum scans can be accomplished in about 40 hours with good statistics. Some "high resolution" measurements, such as the early H_2O trial, are less worthwhile because of the resolution loss. Clearly, also, it would be desirable to reduce the background level.

5. REACTOR SOURCE IMPROVEMENT PROGRAM

As an important adjunct to the spectrometer design, methods for improving the reactor source conditions have been extensively studied. This work has included (a) survey calculation of simple reflector materials and geometries, (b) a theoretical model for treating the re-entrant tube leakage current at the reactor source plane, and (c) a search for reflector "buffer" materials near the source plane. Out of this effort a very promising reflector design, using heavy water and tangential beam port extensions has been evolved. This design is the basis for a proposed reflector modification currently before the Division of Licensing and Regulation of the AEC. According to computer calculations this design should enhance the thermal intensity by approximately a factor of three and, more significantly, reduce the fast background by a factor of ten to twenty.

Figure 6 is a plan view of the proposed reflector tank. In effect, the tank approaches the advantages of tangential ports in a D_2O core, as currently being built into the Brookhaven HFBR facility. The modification is relatively cheap and easy to install. It is believed to be a design advantage of considerable potential importance for swimming pool facilities.

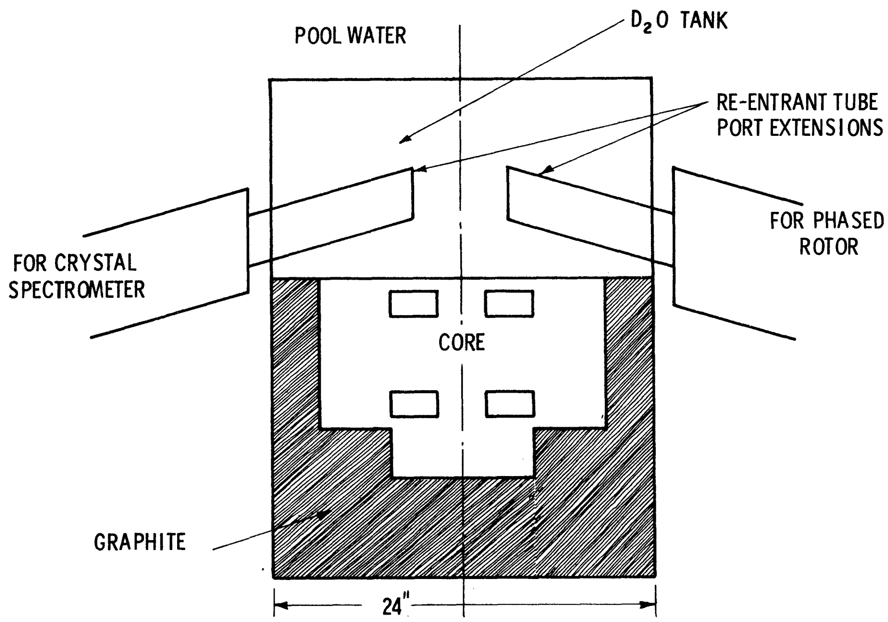

Figure 6. Plan view of D_2O reflector installation.

B. OUTLINE OF EXPERIMENTAL RESULTS AND PUBLICATIONS

Very little concrete experimental work can be reported at this time, because most of the time and energy of the project has been spent developing a usable spectrometer. We may list the following publications, however:

1. "Structure in the Neutron Elastic-Scattering Peak in H_2O," by J. S. King, W. Myers, R. K. Osborn, and S. Yip, Paper KAI, Bull. Am. Phys. Soc., II-8, 41, January 23, 1963.

2. "The Effect of the Port Void in the Prediction of Thermal Neutron Beam Port Current," by Sanford C. Cohen, Ph.D. Thesis, University of Michigan, Ann Arbor, 1964.

3. "A Thermal Neutron Spectrum Measured by a Crystal Spectrometer," by J. L. Donovan, J. S. King, and P. F. Zweifel, ORA Technical Report 03671-3-T, University of Michigan, Ann Arbor, 1963.

C. EXPERIMENTS AND PUBLICATIONS IN PROGRESS

Two scattering experiments were planned for and begun at the close of the project period. These will be completed under NSF Grant GP-1032, probably by the end of 1964. They are:

1. Neutron Scattering from Polyethylene. This work will constitute the main effort of a Ph.D. thesis by John L. Donovan. It will examine the frequency distribution function from various C_nH_{2n} samples for incident neutrons in the energy range 0.03 to 0.1 eV. Both elastic scattering and inelastic scattering cross sections versus incident energy, temperature, and sample crystallinity will be reported.

2. Neutron Scattering from Ethane Gas Targets. This work will constitute part of the Ph.D. thesis effort of Edward Straker. Measurements in the crystal spectrometer will be compared with similar data from the phased rotor facility at The University of Michigan. Targets will have variable pressures up to 50 atmospheres, in the hope of observing onset of liquid interactions near the critical point.

Papers on the results of (1) and (2) are planned for the summer and winter of 1964.

The following paper has been submitted for publication in Nuclear Science Engineering: "Beam Port Current Perturbations," by S. C. Cohen and J. S. King.

D. PROJECT HIGHLIGHTS

Despite the overly long construction and development period for the spectrometer, two results are believed to be significant and should properly be called "highlights":

1. The demonstration that it is possible to make good measurements of incoherent, inelastic scattering cross-sections with a crystal spectrometer at a low power swimming pool reactor. This has not been done before and many people would question its feasibility.

2. The development of a cheap heavy water reflector modification in standard light water swimming pool reactors, to enhance the source properties for neutron scattering experiments.

E. CONTRIBUTING STAFF

The following is a list of student and faculty who have contributed to the project program. The listing is for each year the project was in effect and gives the approximate percentage of full time (for 12 months) financial support provided. For graduate students "full time" pay corresponds to approximately $5,500 per year, in keeping with the project budget.

	Financial Support
May, 1960 - May, 1961	
P. F. Zweifel, Professor, Department of Nuclear Engineering	0%
J. S. King, Associate Professor, Department of Nuclear Engineering	15%
John Donovan, graduate student	25%
William Myers, graduate student	50%
George Wang, graduate student	80%
May, 1961 - May, 1962	
P. F. Zweifel, Professor, Department of Nuclear Engineering	0%
J. S. King, Associate Professor, Department of Nuclear Engineering	15%
John Donovan, Ph.D. candidate	30%
William Myers, graduate student	75%
Richard Rubin, graduate student	15%
Edward Straker, graduate student	5%
Lun-Haw Tang, graduate student	10%
George Wang, graduate student	5%
May, 1962 - May, 1963	
P. F. Zweifel, Professor, Department of Nuclear Engineering	0%
J. S. King, Professor, Department of Nuclear Engineering	15%
Sanford Cohen, Ph.D. candidate	0%
John Donovan, Ph.D. candidate	15%
William Myers, Ph.D. candidate	70%
Edward Straker, Ph.D. candidate	5%
George Wang, graduate student	5%