# THE EFFECT OF STIMULUS PRETRAINING ON
# DISCRIMINATION LEARNING
# IN RETARDATES

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TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# CHAPTER I

## THE PROBLEM

### Background of the Problem

Prior to 1940, investigators of verbal learning generally accepted the proposition that " . . . attaching a new response to an old stimulus, according to the A-B . . . A-K paradigm, would lead to negative transfer" (Arnoult, 1957; p. 339). During the early 1940's, however, several investigators (Birge, 1941; Gibson, 1940; 1942) obtained positive transfer using the A-B . . . A-K paradigm. This positive transfer phenomenon was referred to as stimulus predifferentiation (PD).

Two major theories arose in explanation of the PD phenomenon. Both of the theories agreed that a "predifferentiation" process occurred but they disagreed concerning the manner in which the pretraining produced it. Gibson (1940) hypothesized that the pretraining predifferentiated the stimulus list by reducing the "intra-list generalization." Miller and Dollard (1941) and Miller (1948) hypothesized that the pretraining predifferentiated the stimulus list by producing "acquired distinctiveness."

A substantial number of experiments have been conducted since that time and most of them bear out the presence of the positive transfer phenomenon, but to the present time none of them have resolved the problem of the manner in which the stimulus pretraining produces the facilitation (Ellis, 1965; Postman, 1963).

PD has been found to result in a wide variety of specific experimental structures, and from various types of pretraining. The most frequently used stimuli have been visual, but a number of other stimulus modalities have been included, such as tactual shapes (Ellis, Bessemer, Devine & Trafton, 1962), and weight differences (Albert, 1959). Pretraining responses have included nonsense syllables at different association values (Jeffrey, 1957), observation and other types of covert responses as inferred from different instructions (Goss & Greenfeld, 1958), and aesthetic judgments (Rasmussen & Archer, 1961). Transfer task responses have included recognition and identification (Hake & Eriksen, 1956). and GSR (Yarczower, 1959). The largest group of experiments have used verbal pretraining on visual stimuli followed by discriminative motor responses to the stimuli during the transfer stage (Battig, 1956; Ellis, 1965; Holton & Goss, 1956; McAllister, 1953; Murdock, 1958).

Several explanatory mechanisms have been hypothesized--for example, "increased meaningfulness" (Arnoult, 1953), "attention to cues" (Hake & Eriksen, 1955), "performance set" (J. H. Cantor, 1955; Smith & Goss, 1955), and facilitation of "class schema learning" (Arnoult, 1957; Attneave, 1957). Several authors (Arnoult, 1957; Ellis, 1965; Gibson, 1963; Murdock, 1957; Postman, 1963; Vanderplas, 1958) have made attempts to collate the accumulating hypotheses and empirical evidence. Their discussions indicate that none of the hypotheses account for all of the empirical findings and they suggest that PD may be a complex phenomenon involving interactions among a number of stimulus, response, and subject parameters.

This trend toward viewing the phenomenon as a function of composite variables is revealed in several recent experiments. The investigators devised methods of measuring and manipulating variables that reflect intra-task, inter-task, or task-subject relationships and studied pretraining effects at different levels of these measurements. For example, Murdock (1958) manipulated task difficulty, and Vanderplas and Garvin manipulated association value of nonsense forms. Pfafflin (1960) obtained evidence that the pre-training effect is a function of "stimulus meaningfulness" and "appropriateness of labels." Pfafflin's criterion of stimulus meaningfulness was the intersubject consistency with which subjects supplied the same label for a stimulus when asked to name it. The modal label supplied by subjects for a stimulus was considered by Pfafflin to be the most appropriate or relevant label for that stimulus.

The literature presents evidence that the presence and magnitude of the phenomenon, within a particular structure of experimental conditions, may be a function of subject variables such as age and intelligence levels. PD with normal adult subjects (J. H. Cantor, 1955; Gagne & Baker, 1950; Rossman & Goss, 1951), or with normal children (G. N. Cantor, 1955; Norcross & Spiker, 1957; Weir & Stevenson, 1959). Only three experiments using retarded subjects have been reported, two with adult retardates (Cantor & Hottel, 1957; Smith & Means, 1961), and one in which the subjects were retarded children (Dickerson, Girardeau, & Spradlin, 1964).

The phenomenon has been definitely shown to be present in retardates but with little experimental evidence. The present study attempts to further define the function of age and mental level in institutionalized retardates in relation to PD.

## Development of the Study

The first step taken in this investigation was to adapt the general method of Pfafflin's (1960) PD experiment with college student subjects for use with mentally retarded children and adolescents.

Pfafflin's method provided an orthogonal arrangement of four pretraining conditions (relevant label, irrelevant label, observation, and no pretraining), and three levels of stimulus form (high, medium, and low). Relevant labels were the modal labels supplied by a separate sample of subjects in the preliminary scaling procedure; these labels were nominative or descriptive words with varying degrees of association to the stimuli corresponding to the index of labeling consistency. Irrelevant labels consisted of a list of ten adjectives, such as "fresh" and "true," used for all three levels of stimulus form. Pfafflin's subjects subsequently performed a motor discrimination task in which they were to learn which of two buttons to press in response to each of the ten stimuli of the form level to which the subject had been assigned. The dependent measure was the total number of errors on the last eleven of twelve learning trials.

Pfafflin found that the effectiveness of observation and labeling pretraining was interrelated with the form level of the stimuli. Pretraining in which subjects learned labels that were relevant to the low form level stimuli appeared to facilitate motor discrimination performance on a subsequent task with the same stimuli. The same kind of pretraining with high form level stimuli produced no facilitation, and may have even produced interference on the subsequent discrimination task. The relationship between relevant label pretraining and no pretraining at the medium form level was intermediate between the relationships at the high and the low form levels. With Pfafflin's subjects, the transfer effect of relevant label pretraining appeared to vary in an inverse relationship with the form level of the stimuli.

Retarded subjects at different levels of age and IQ scores, having had different levels and patterns of experiences, could be expected to have different levels of previously established observing and labeling tendencies. For this reason, application of the PD paradigm to a retarded population, following Pfafflin's entire method, was thought to provide a test of the universality of the PD phenomenon over differing populations.

The second step in the development of the plan for the study was to devise an experimental structure which would isolate possible sources of effects which have been confounded in previous studies. The review of the literature suggested that divergences among experimental results may be due to the interaction of several variables: relevancy of pretraining labels to pretraining stimuli; relevancy of pretraining labels to transfer task stimuli; and relevancy of pretraining stimuli to transfer task stimuli. Few previous studies provided simultaneous control of these three variables, and no study was found that isolated and attempted to measure the possible interactions of these variables. Experiments that have investigated relevant vs irrelevant label pretraining, have confounded that effect with the effect of relevant stimulus pretraining and with the effect of pretraining labels which are relevant to the discrimination task stimuli.

In order to provide partial isolation of these possible effects, the design of the present experiment contained three types of pretraining conditions: relevant label, irrelevant label, and no pretraining. The design also contained two types of stimulus conditions: one condition being that the pretraining stimuli and the transfer task stimuli were identical, and the second condition being that the pretraining stimuli and transfer task stimuli were different. The potential contributions of identical vs different stimuli, relevant vs irrelevant relationship of the labels to the pretraining stimuli, and relevant vs irrelevant relationship of the labels to the transfer task stimuli, were systematically varied by the experimental conditions.

Inclusion of two levels of stimulus form in the design provided a total of twelve treatment combinations. The manner in which these treatment combinations isolate the possible effects is presented in Chapter III in the section on Design.

## The Present Study

The study was conducted at the Parsons State Hospital and Training Center, Parsons, Kansas, a residential institution for mentally retarded,[1] brain damaged, emotionally disturbed children and adolescents, ages 6 to 21 years. The subjects in the experiment were mentally retarded children and adolescents who were patients in the residential hospital.

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1. The term mental retardation is used throughout this paper as defined by Heber, R. A manual on terminology and classification in mental retardation. Monograph supplement to Amer. J. ment. Defic., 2nd. ed., 1961.

The objective of this study was to assess the transfer effects of selected relationships among (a) pretraining response, (b) pretraining stimulus, (c) transfer task stimulus, and (d) subject variables.

Experimental subjects received pretraining on a paired-associates task composed of five visual form stimuli and verbal labeling responses. Subsequent to the pretraining stage of the experiment, all subjects, including the control subjects who received no pretraining, performed a paired-associates transfer task composed of five visual form stimuli and button pressing responses. Error scores were computed from each subject's performance on the transfer task.

The following questions were investigated:

(1) Does stimulus pretraining facilitate learning by mentally retarded children and adolescents of a subsequent motor discrimination task with the same stimuli?

(2) Is the pretraining effect a function of:

(a) the relevance of pretraining stimuli to the transfer task stimuli?

(b) the relevance of pretraining verbal labels to the pretraining stimuli?

(c) the relevance of pretraining verbal labels to the transfer task stimuli?

(d) the form level of the stimuli?

(e) the subject's age?

(f) the subject's verbal IQ level?

(g) interactions among these variables?

## CHAPTER II

## REVIEW OF THE LITERATURE

This review of the literature is an attempt to look at the general background of PD (stimulus predifferentiation) investigations, the specific problems studied by various PD investigators, and to show the relevance of these studies--particularly Pfafflin's work--to the present experiment.

Vanderplas (1958) stated that PD studies have been interpreted in two major ways: (a) as demonstrating areas of transfer phenomena, and (b) as demonstrating areas of perceptual learning phenomena.

The PD method, in terms of the relationships which the transfer approach has represented, is considered first. Here the effect of practice in one activity upon subsequent performance in another activity is called transfer. Transfer has generally been supposed to operate in many everyday life processes, especially in educational and developmental processes.

The traditional experimental method for investigating transfer is to place subjects from equated groups in controlled situations which permit analysis of the preceding activity (Task 1) and the subsequent activity (Task 2) into lists of relatively discrete stimulus-response connections. This method provides operational definitions of functional equivalence and nonequivalence of the tasks, stimuli responses, and subjects (Osgood, 1953). The basic design of transfer experiments is presented in Table I, by a schema adapted from Murdock (1957) and Osgood (1953).

TABLE I

A SCHEMATIC REPRESENTATION OF THE BASIC DESIGN OF TRANSFER EXPERIMENTS

| Subject Groups | Preceding Activity | Transfer Task |
|---|---|---|
| Experimental | Task 1<br>$S_1$--$R_1$ | Task 2<br>$S_2$--$R_2$ |
| Control | Task 1'<br>$S_x$--$R_x$ | Task 2<br>$S_2$--$R_2$ |

Task 1 refers to the preceding activity of experimental groups, and Task 1' refers to the preceding activity of control groups. The effect of the differences between the preceding activities on the performance of Task 2 can be detected by comparisons between experimental and control groups on measures of acquisition or performance of Task 2. If the experimental group acquires Task 2 in fewer trials or performs with fewer errors than the control group, the pretraining on Task 1 is said to have positively transferred to Task 2. The reverse situation is said to be an instance of interference or negative transfer (Lawson, 1960; Woodworth & Schlosberg, 1954).

The basic transfer design may be adequate to demonstrate the presence of a transfer effect, but is inadequate to identify the critical variables underlying the effect. Discovery of the critical variables requires specification of many relationships within the application of transfer designs. Intratask-subject, intertask-subject, stimulus-subject, and response-subject relationships, and other components of the experimental structure are all potential sources of effects reflected in the measure of transfer. Murdock (1957) pointed out that transfer depends on the interrelationships among Task 1, Task 1' and Task 2, and he emphasized that alterations in any of these tasks alters each of the intertask relationships.

The PD paradigm, along with discrimination reversal, transposition, learning set, stimulus generalization and response generalization, has been viewed as a standard variation on the basic transfer design (Lawson, 1960; Stevens, 1960; Woodworth & Schlosberg, 1954). Murdock (1957) expressed the view that the possible effects of these other experimental relationships should be distinguished from the PD effect.

The PD paradigm has been differentiated from other types of transfer studies by three conventions. Two of the conventions specify relationships between Task 1 and Task 2 presented to the experimental groups. These intertask relationships are: (a) the stimuli of Task 1 and Task 2 are identical, and (b) the response of Task 1 and Task 2 are dissimilar to the extent that there could be no generalization between them (Arnoult, 1957). The response specification is usually met by selecting $R_1$ and $R_2$ from different response modalities. Thus, Task 1 cannot be interpreted as providing additional practice in making Task 2 responses. The third convention was proposed by Murdock (1957) to differentiate PD studies from motor transfer studies. This convention specifies that in Task 2, PD studies utilize simple motor responses which have been learned prior to the experiment. Motor transfer studies on the other hand utilize more complex motor responses which are learned during the experiment. The distinction implied by this convention is that in PD studies associations are learned, but in motor transfer studies, the response itself is learned. These three conventions--(a) same stimuli, (b) different responses, and (c) simple Task 2 responses--identify PD studies within the area of transfer.

Vanderplas (1958), as mentioned earlier, also indicated that PD has been viewed as related to perceptual learning. He enumerated five perceptual processes, one or more of which is unavoidably involved in the experimental task of transfer studies. These perceptual processes are: detection, recognition, discrimination, identification, and judgment.

The qualities of discriminability, similarity, and meaningfulness do not reside in the stimulus alone, but are part of stimulus-subject relationships. Scandura (1965) and Underwood (1963) pointed out that discrepancies can exist between the apparent or nominal stimulus and the actual or functional stimulus. Murdock's (1957) differentiation between motor transfer and PD studies leads to the conclusion that task difficulty and task complexity do not reside in a response component alone, but instead reflect response-subject, intratask-subject, and intertask-subject relationships. Taken together these considerations point up the need for quantitative description of these kinds of relationships. These relationships can be measured in independent samples and/or by testing subjects before and after the experiment.

Vanderplas (1958) makes explicit a distinction between the transfer and perceptual learning approaches which appears implicitly in the literature. He proposed that studies examine transfer processes when stimulus properties and intralist relationships have been learned by subjects prior to the experiment; and that studies primarily examine perceptual learning processes when stimulus properties and intralist relationships are learned by the subjects during the experiment. Vanderplas' delineation would indicate that PD studies examine transfer processes when subjects learn to associate initially distinctive or discriminable stimuli with initially available responses, and that PD studies examine perceptual learning processes when subjects learn identification or discriminations of the stimuli themselves.

Vanderplas and Garvin (1959) stated that the literature to that time indicated that the PD phenomena appeared to be a complex interactive effect among a number of independent variables including subject relationships to the particular tasks and other features of particular experimental structures. This conclusion would suggest that the transfer and perceptual learning approaches to PD are not mutually exclusive, but are complementary. Vanderplas (1958) and Postman (1963) suggest that the delineation of perceptual learning and transfer processes represents the critical relationship investigated by PD studies.

Arnoult (1957), Gibson (1963), and Murdock (1957) also indicate that measurable constructs are derivable from perceptual responses and perceptual motor responses, and that applications of the PD method in conjunction with measures of perceptual processes may yield information concerning both transfer and perceptual learning. The major trend in the PD literature is that relationships between transfer and perceptual learning processes can be investigated by PD experiments.

The background review indicates that the perceptual learning and transfer approaches have overlapped with resulting ambiguity and confusion, and that a more useful kind of analysis has emerged from the literature. Applications of the PD paradigm appear to involve a combination of stimulus-subject, response-subject, intratask-subject, and intertask subject relationships. PD studies which have controlled for these relationships are the more interpretable and comprehensive investigations in the area. These investigations are also generally concerned with the effects of: subject population; type of stimuli; type of transfer task; type and amount of pretraining; verbal mediation; and the relationships existing among these factors.

Studies appear to support a high expectation that the PD phenomenon could be demonstrated in most segments of the normal human population. The evidence for the presence of PD in normal adults, normal children, and mildly retarded adults is substantial. Examples of studies that have found PD in normal adults are J. H. Cantor (1955), Gagne & Baker (1950), Goss (1953), Robinson (1955), Rossman & Goss (1951), and Yarczower (1959). Examples of studies that have found PD in normal children are G. N. Cantor (1955), Norcross & Spiker (1957), Reese (1961), and Weir & Stevenson (1959). Two experiments found the PD effect in mildly retarded adults (Cantor & Hottel, 1957; Smith & Means, 1961). Although several experiments did not find PD in particular samples of normal adults and/or normal children (Albert, 1959; Arnoult, 1953; Weir & Stevenson, 1959), these failures appear to be more plausibly attributed to other sources such as task difficulty beyond the particular population's level of ability, fatigue, or boredom, instead of an absence of PD in segments of the populations studied.

The effectiveness of the PD pretraining does not appear to be a function of the stimulus modality. Most studies have utilized visual stimuli, including light intensity (Goss & Greenfeld, 1958), geometric visual forms (Cantor & Hottel, 1957), light patterns (Murdock, 1958), visually presented fingerprint forms (DeRiveria, 1959; Robinson, 1955), letter orientation (Hayes, Robinson & Brown, 1961), pictures of people (Norcross & Spiker, 1957), pictures of animals (Weir & Stevenson, 1959), pictures of familiar objects (Pfafflin, 1960), and nonsense forms (Arnoult, 1953; Rasmussen & Archer, 1961; Yarczower, 1959). Other studies have utilized auditory stimuli, (Liberman, Harris, Kinney & Lane, 1961; Lane & Moore, 1961; Christovitch, Klass & Alekin, 1961), and tactual-shape stimuli (Ellis, Bessemer, Devine & Trafton, 1962). Albert (1959) failed to find PD with weight stimuli, but the failure appears to be more plausibly attributed to discriminability between the stimuli below the particular subject's threshold, instead of an absence of PD with particular stimulus modalities. PD has been shown to be a function of stimulus relationships such as intralist similarity, but there is little evidence that the phenomena is absent in particular stimulus modalities.

PD experiments have most often used motor discrimination transfer tasks (Murdock, 1958), but recognition transfer tasks have also been used (Ellis, et al, 1962; Vanderplas, 1958; Vanderplas & Garvin, 1959). Yarczower (1959) measured galvanic skin response (GSR) in the transfer stage. The effectiveness of PD training does not appear to be a function of the transfer task response itself.

The typical PD experiment involves pretraining in which the experimental group learns to attach verbal labels to the stimuli. The verbal labels may be experimenter supplied or subject supplied. The experimenter supplied labels used have ranged from direct verbal representations of the transfer task response (Gagne & Baker, 1950) to nonsense syllables with low associative value so that they could have very little relationship to either the transfer task or stimuli (Jeffrey, 1957).

Arnoult (1957) categorized the pretraining used in earlier predifferentiation experiments into five classes: (a) relevant S-R, (b) relevant S, (c) irrelevant S, (d) attention, and (e) no pretraining.

Relevant S-R pretraining presents the same stimuli to be used in the transfer task, and the verbal responses are representative of motor responses to be given in the transfer task. Gagne & Baker (1950), Baker & Wylie (1950), Battig (1956), and McAllister (1953) have included this type of pretraining in their designs. Relevant S-R pretraining has been found to be superior to the other types of pretraining, but its use has been questioned on the basis that response generalization may account for the transfer effect rather than PD effect (Arnoult, 1957).

Other recent studies have also used relevant S pretraining involving the following responses: nonsense syllables (Bailey & Jeffrey, 1958; G. N. Cantor & Hottel, 1957; Reese, 1961; Rasmussen & Archer, 1961), names for the stimuli (Albert, 1959; Norcross & Spiker, 1957; Ellis, Bessemer, Devine & Trafton, 1962; Pfafflin, 1960; Robinson, 1955; Weir & Stevenson, 1959; Yarczower, 1959), and letters for the stimuli (DeRiveria, 1959).

Arnoult (1953) studied the effects of verbal pretraining with nonsense forms on subjects' (airmen) performance on a motor discrimination task. The experimental subjects were given ten pretraining trials on a paired-associates list composed of the five stimuli used in the subsequent task (relevant S) and five letters of the alphabet. One control group was given pretraining on a different set of stimuli (irrelevant S), and the other control group received no pretraining. The pretraining groups averaged approximately seven out of ten correct responses on the last two pretraining trials. The transfer task consisted of pressing the "same" button when a prototype of the relevant stimuli was paired with an identical copy of the prototype, or pressing the "different" button when the prototype was paired with one of the irrelevant stimuli. No facilitation effect was found.

Arnoult (1953) reported a second experiment that was similar to the first with similar subjects, stimuli, and pretraining, but with a different transfer task. Again an average of approximately seven out of ten correct responses on the last two pretraining trials was reached by the pretraining groups. The transfer task consisted of learning which of five keys was correct for each of the five stimuli. Again, no significant differences in performance were related to types of pretraining.

Yarczower (1959) used Arnoult's nonsense forms in an experiment with college students. Two experimental groups were pretrained to associate meaningful but irrelevant words with relevant stimuli. Two control groups were pretrained in the same manner but on irrelevant stimuli. A high pretraining criterion (fifteen out of fifteen correct responses) and a low pretraining criterion (five out of five correct responses) completed the design. The transfer task was a discrimination conditioning procedure in which one of the relevant stimuli (CS) was conditioned to shock (UCS), and the dependent measure was the reduction in generalization of the GSR (UCR) to the four other relevant stimuli. The relevant stimulus pretraining group that had been pretrained to the higher criterion showed significantly greater differentiation (or reduced generalization).

The Arnoult (1953) and Yarczower (1959) experiments have been interpreted by Gibson (1963) as showing that PD may be found in one type of transfer task where it cannot be detected in another type. Other studies have shown that variations among results from experiments using similar transfer tasks have often been as great as variations between results from different transfer tasks (Goss & Greenfeld, 1958). The transfer task response itself would thus not appear to be critical for obtaining a stimulus predifferentiation effect, but the relationships among features of both tasks and subject variables appear to influence the occurrence and amount of transfer.

Irrelevant S pretraining is more appropriately considered a control procedure aimed at assessing the effect of familiarization with the transfer stimuli that relevant S-R and relevant S groups receive. With this type of pretraining, stimuli different from the ones to be used in the transfer task are presented to the subjects. The pretraining responses used are either identical or comparable to the pretraining responses for the relevant S group. Norcross & Spiker (1957) using children provided a clear example of this type of control procedure. One group received pretraining with a pair of pictures of boys, and learned to call them "Jack" and "Pete." The transfer task for all three groups in the study involved responding to a pair of pictures of girls, which the other groups had learned to call "Jean" and "Peg."

In attention pretraining, the subject is not required to make any overt response but is instructed to attend to the stimuli. This type of pretraining is also considered to be a control procedure aimed at equalizing the amount of exposure to the transfer task stimuli. This control procedure has been criticized because of the obvious dependence on the experimenter's instructions without any objective means of directly assessing how well or in what manner the subjects respond to the instructions. Goss & Greenfeld (1958), included four variations on this type of pretraining. The instructions for these groups ranged from merely telling the subject to look at the stimuli, to telling the subject to look at, discriminate among, and covertly give different names to the stimuli. The group whose instructions were merely to look at the stimuli did not differ from the control group that received no pretraining. This finding suggests that some instructions are not sufficient additions to the stimulus complex and pre-experimental response disposition to arouse attention to a level that facilitates the subsequent activity. The groups whose instructions included to discriminate and to name, did show positive transfer, but there was no significant difference among these groups. There were also no differences among the four relevant S groups, but each kind of relevant S pretraining produced more positive transfer than did any of the attention pretraining methods.

Earlier studies (Birge, 1941; G. N. Cantor, 1955; Goss, 1953; Kurtz & Hovland, 1953; Robinson, 1955; and Rossman & Goss, 1951) which directly compared attention and relevant S pretraining, obtained equivocal findings with about half of the comparisons showing attention pretraining as effective as relevant S pretraining, and the other half showing relevant S pretraining to be superior.

No pretraining is the basic control procedure aimed at assessing the effect of the other forms of pretraining. Osgood (1953) noted that no pretraining subjects are actually engaged in unspecified activities, and he stated that this control procedure does not provide adequate specification of the differences between the preceding activities of the experimental and control groups. Nevertheless, inclusion of no pretraining control appears to provide a necessary baseline. The control problem posed by Osgood becomes relevant when comparisons are made between groups that may conceivably engage in different kinds of unspecified activity. Such a situation may occur when samples from different populations are compared, for example, with subject groups of different ages, or of different intellectual levels, or of different environmental and cultural experiences as with children in residential institutions in contrast to children living at home. This control problem probably is confounded with such questions as task difficulty and pre-experimental response dispositions to particular stimuli of particular subject populations.

In general, the literature indicates that the most effective type of pretraining is the relevant S-R, followed by relevant S, and then attention pretraining. But this general conclusion has not always been supported. For example, in a study with children (Norcross & Spiker, 1957) for the older age group, irrelevant S pretraining was superior to one form of relevant S pretraining. Apparently the amount of transfer produced by types of pretraining is sensitive to a number of factors that have not been consistently controlled in many of the studies. Findings concerning the amount of predifferentiation training and type of predifferentiation training are not generalizable without considering subject variables, level of discriminability, complexity, and difficulty of the tasks, and the interaction between such factors.

Studies with children present much of the same view of the PD phenomenon as those with adults. G. N. Cantor (1955), Dietz (1955), Gerjouy (1964), Jeffrey (1952), Norcross & Spiker (1957), Reese (1961), and Weir & Stevenson (1959) have each demonstrated that children discriminate among stimuli more rapidly if they are given stimulus naming pretraining.

Norcross & Spiker (1957) randomly assigned preschool subjects of chronological ages from 3.5 to 5.5 years to relevant stimulus, same-different label, and irrelevant stimulus naming groups. The transfer stimulus objects were similar pictures, one of which was rewarded if selected. Subjects were given pretraining trials until 12 consecutive correct pretraining responses were given, but only subjects meeting the criterion within 60 pretraining trials were retained for the transfer stage. The results showed a significant difference between the pretraining groups, with the relevant label groups making a significantly greater number of correct responses in the 30 transfer trials than either of the other groups. A highly significant age factor was also found, with the older subjects making more correct responses within each group. The study had 26, 26, and 18 subjects respectively in the relevant stimulus, irrelevant stimulus, and same-different treatment conditions. The differences in number of trials to pretraining criterion were not significant, but they were in the same direction as the results of the transfer trials; and thus the data suggest, particularly for the younger groups, that this factor could have altered the pattern of the findings.

Weir & Stevenson (1959) gave pretraining sessions to children within the age years of three, five, seven, and nine. There were 32 subjects in each group. The pretraining for half of each group included instructions to name the stimulus object as they responded to it by pressing one of two panels and learning which panel position, upper or lower, would turn off the stimulus light. The other subjects received the same pretraining, except without naming the objects. The same stimulus objects, five pairs of pictures of animals, were used in the transfer task. The groups that named the stimuli in pretraining made significantly greater numbers of correct responses in the transfer stage. Five year old subjects made more correct responses than either younger or older groups, but the pretraining variable showed less effect at the five year level. The authors suggested that the task was too simple for the older groups. The older subjects, when later asked about the experimental tasks, indicated that they had been devising complex hypotheses about the task. The authors also considered that the curvilinear facilitation with age function could have been an artifact related to interaction between task difficulty and age. The study did not include a control group receiving no pretraining. It is also conceivable that the large number of trials (up to 200) on the simple tasks may have influenced the results in a way that such a control group would have demonstrated. The study demonstrates the problem of choosing a task for different age groups that differ only in discriminability.

Dickerson, Girardeau & Spradlin (1964), working with retarded children, investigated the effect of verbal pretraining on a subsequent two choice discrimination between geometric forms. The verbal labels used were numbers "one" through "ten." Two numbers were used as names for two stimulus figures by each subject. The stimulus figures were solid black geometric shapes. The transfer task stimuli were a pentagon and a hexagon. Irrelevant stimuli used in the pre-training were an octagon, a square, and two rectangular forms that differed from the square and each other in height. The pentagon, hexagon and octagon were of the same diameter. The rectangular forms were larger than the other figures. Four classes and a total of twelve types of pretraining were given. The four classes of pretraining were: (1) relevant stimulus pretraining with the positive stimulus and irrelevant stimulus pretraining instead of the negative stimulus, (2) relevant stimulus pretraining with the negative stimulus and irrelevant stimulus pretraining instead of the positive stimulus, (3) relevant stimulus pretraining for both the positive and negative stimuli, and (4) irrelevant stimulus pretraining using the rectangular forms. All possible combinations of stimuli within these classes were used. The study found that the verbal pretraining effect was not significant, but was in the direction of positive transfer. Thus, Dickerson, et al, (1964) compared relevant positive stimulus pretraining, relevant negative stimulus pretraining, relevant positive and negative stimulus pretraining, and irrelevant stimulus pretraining. The relevant positive and negative, the relevant positive, and the irrelevant groups showed significant improvement over trial blocks but the relevant negative group show nonsignificant change. The relevant positive-and-negative pretraining was superior to all other forms of pretraining over trials 60-100.

Dickerson, et al, (1964) differed from most PD studies by using simultaneous presentation of stimuli in pretraining and also in the transfer task. The nonsignificant results suggest that the stimulus pretraining effect may be more pronounced with successive presentation. The failure to find clear evidence of a facilitation effect could also have been related to the use of a noncorrection procedure. Dealing with geometric forms may be particularly difficult for mentally retarded children. Since the numbers were not symbolic or descriptive of either the stimuli or the responses, they could possibly have an interference effect. Numbers could conceivably conflict with position order, rank size, number of sides, or rank number of sides. Since this was the only study found with retarded children, the possibility remains that the PD effect may be absent in a large portion of younger retardates.

Cantor & Hottel (1957) found that retarded adult males who received stimulus pretraining with nonsense syllables were superior on a subsequent discrimination task to subjects who received irrelevant stimulus pretraining with the same nonsense syllables. M. P. Smith & Means (1961) found with retarded adults that relevant stimulus pretraining with meaningful names (relevant labels) was superior to irrelevant stimulus pretraining with nonsense names (irrelevant labels) and found no difference between relevant stimulus pretraining with nonsense names and irrelevant stimulus pretraining with nonsense names.

The three PD studies of retarded subjects suggest that relevant stimulus pretraining has a facilitation effect on subsequent discrimination learning for retardates, and that the effect was increased by learning meaningful names for the relevant stimuli.

Pfafflin's (1960) study which is discussed in Chapter I, provided the model for the present investigation. In that study subjects from a college student population were assigned to twelve treatment groups equal in number. The dimensions studied were relevancy of pretraining labels and form level of stimuli. Sets of high, medium, and low form level stimuli were selected according to the consistency with which an independent sample of subjects gave the same label for a stimuli when asked to name it. Relevant and irrelevant labels were attached to each stimulus in the three form levels. Subjects were divided randomly into groups that were given no pretraining, observational opportunity only, or pretraining with the labels. The distribution of subjects into treatment groups is shown in Table II below. Following the pretraining stage of the study, the subjects learned to press one of two buttons in response to each stimulus in their form level group. Error scores were computed and an analysis of variance applied.

TABLE II

DISTRIBUTION OF PFAFFLIN'S SUBJECTS INTO TREATMENT CONDITIONS

| Pretraining | Form Classes | | |
|---|---|---|---|
| | High | Medium | Low |
| None | 10 | 10 | 10 |
| Observation | 10 | 10 | 10 |
| Irrelevant Labels | 10 | 10 | 10 |
| Relevant Labels | 10 | 10 | 10 |

Pfafflin's results show an inverse relationship between the number of errors made in learning the button pressing response and the form level of the stimuli. Learning of relevant labels and observation pretraining, in contrast with no pretraining, produced significant decreases in errors. The inverse relationship was linear for observation pretraining, but departed significantly from linearity for pretraining with relevant labels. Learning relevant labels produced increasingly greater decreases in errors at the medium and low form levels. Pfafflin interpreted the results as supporting the view that the meaning of stimulus (form level) and the meaning of pretraining responses (label relevancy) must be considered in relation to each other before the processes underlying this PD phenomenon can be understood.

# CHAPTER III

## METHOD

The objective of the present study was to assess the transfer effects of selected relationships among (a) pretraining response, (b) pretraining stimulus, (c) transfer task stimulus, and (d) subject variables in a retarded population.

The present investigation is described under the following section headings: (a) Subjects; (b) Design; (c) Apparatus and Materials; and (d) Procedure.

### Subject

The 96 subjects in the study (52 males and 44 females) were retarded children and adolescents selected from a population comprised of all of those residents of Parsons State Hospital and Training Center, Parsons, Kansas, who met the following criteria: (a) CA in the range from 11-6 to 20-6; (b) WISC or WAIS verbal IQ score in the range from 50 to 84; and (c) absence of physical conditions or severe emotional disturbances which would make them unable to comply with the experimental procedure.

The population was divided into four groups: (a) younger-higher; (b) younger-lower; (c) older-higher; and (d) older-lower patients. Younger refers to patients in the CA range from 11-6 to 16-6, and older refers to patients in the CA range from 16-7 to 20-6. Higher refers to patients with verbal IQ scores from 65 to 84, and lower refers to patients with verbal IQ scores from 50 to 64.

Subjects were placed into 12 treatment conditions (8 Ss per treatment). Each treatment condition contained 2 Ss from each of the 4 classifications (younger-higher, younger-lower, older-higher, and older-lower), selected randomly.

Table III presents the CA and IQ distributions of the 4 groups of Ss. No statistically significant differences were found between the CA means for the younger-higher and younger-lower Ss, nor between the older-higher and the older-lower Ss. No statistically significant differences were found between the IQ score means for the younger-higher and the older-higher Ss, nor between the younger-lower and older-lower Ss. No statistically significant differences were found between IQ and CA means for male and female Ss.

## Design

The experiment was designed to investigate the following questions:

(1) Does stimulus pretraining facilitate the learning, by mentally retarded children and adolescents, of a subsequent discrimination task with the same stimuli?

(2) Is the pretraining effect a function of:

(a) the relevance of the pretraining stimuli to the transfer task stimuli?

(b) the relevance of the pretraining labels to the pretraining stimuli?

TABLE III

DISTRIBUTION OF CA AND VERBAL IQ FOR THE SUBJECT CLASSIFICATION GROUPS

| | | Younger Lower | Younger Higher | Older Lower | Older Higher |
|---|---|---|---|---|---|
| CA[1] | Mean | 13-9 | 14-1 | 18-2 | 18-11 |
| | SD | 24.38 | 17.12 | 14.19 | 12.01 |
| | Range | 11-6/16-6 | 11-7/16-5 | 16-9/20-6 | 16-8/20-4 |
| Verbal IQ | Mean | 57.29 | 72.17 | 57.75 | 73.58 |
| | SD | 4.10 | 5.14 | 3.79 | 5.67 |
| | Range | 50-63 | 65-84 | 52-63 | 65-83 |

[1]CA means and ranges are given in years and months.

(c) the relevance of the pretraining labels to the transfer task stimuli?

(d) the form level of the stimuli?

(e) the subject's age?

(f) the subject's verbal IQ score?

(g) interactions among these variables?

The treatment and subject conditions of the experiment were derived from an orthogonal arrangement of five factors. The five factors and their respective levels were designated as seen in Table IV.

Subjects were nested within all five factors of the design: i.e., each S received only one of the factorial combinations. Factors A, B, and C were independent measures of treatment variation. The factorial combinations of the levels of these treatment variables formed 12 experimental treatment conditions. Factors D and E were independent measures of subject variation. The factorial combinations of the levels of these subject variables formed 4 subject classifications. Random selection of 2 Ss from each of the 4 subject classifications for each of the treatment conditions provided 12 comparable groups with 8 Ss each. Each group received one of the 12 treatment conditions. The experimental conditions under each treatment were as follows:

Treatment 1 refers to factorial combination $A_1B_1C_1$. The group receiving this treatment was given no pretraining, and performed the transfer task with list 1 of the low form stimuli.

Treatment 2 refers to factorial combination $A_1B_1C_2$. The group receiving this treatment was given no pretraining, and performed the transfer task with list 1 of the high form stimuli.

TABLE IV

OUTLINE OF THE TREATMENT AND SUBJECT CLASSIFICATION FACTORS

| Levels | Descriptions of the Factors and Levels |
|---|---|
| | Factor A Type of Pretraining |
| $A_1$ | No Pretraining |
| $A_2$ | Irrelevant Label Pretraining |
| $A_3$ | Relevant Label Pretraining |
| | Factor B Type of Stimulus Relationship |
| $B_1$ | Different Stimuli in Pretraining and Transfer |
| $B_2$ | Identical Stimuli in Pretraining and Transfer |
| | Factor C Form Level of Stimuli |
| $C_1$ | Low Form Stimuli |
| $C_2$ | High Form Stimuli |
| | Factor D Age Level of Subjects |
| $D_1$ | Younger Subjects--CA's 11-6 to 16-6 |
| $D_2$ | Older Subjects--CA's 16-7 to 20-6 |
| | Factor E Verbal IQ Level of Subjects |
| $E_1$ | Lower Subjects--Verbal IQ Scores 50 to 64 |
| $E_2$ | Higher Subjects--Verbal IQ Scores 65 to 84 |

Treatment 3 refers to factorial combination $A_1B_2C_1$. The group receiving this treatment was given no pretraining, and performed the transfer task with list II of the low form stimuli.

Treatment 4 refers to factorial combinations $A_1B_2C_2$. The group receiving this treatment was given no pretraining, and performed the transfer task with list II of the high form stimuli.

Treatment 5 refers to factorial combination $A_2B_1C_1$. The group receiving this treatment was given irrelevant label pretraining on low form stimuli, but performed the transfer task with different low form stimuli. The pretraining labels were relevant to the task 2 stimuli.

Treatment 6 refers to factorial combination $A_2B_1C_2$. The group receiving this treatment was given irrelevant label pretraining on high form stimuli but performed the transfer task with different high form stimuli. The pretraining labels were relevant to the transfer task stimuli.

Treatment 7 refers to factorial combination $A_2B_2C_1$. The group receiving this treatment was given irrelevant label pretraining on low form stimuli, and performed the transfer task with the same stimuli. The pretraining labels were also irrelevant to the transfer task stimuli.

Treatment 8 refers to factorial combination $A_2B_2C_2$. The group receiving this treatment was given irrelevant label pretraining on high form stimuli, and performed the transfer task with the same stimuli. The pretraining labels were also irrelevant to the transfer task stimuli.

<u>Treatment 9</u> refers to factorial combination $A_3B_1C_1$. The group receiving this treatment was given relevant label pretraining on low form stimuli, but performed the transfer task with different low form stimuli. The pretraining labels were irrelevant to the transfer task stimuli.

<u>Treatment 10</u> refers to factorial combination $A_3B_1C_2$. The group receiving this treatment was given relevant label pretraining on high form stimuli, but performed the transfer task with different high form stimuli. The pretraining labels were irrelevant to the transfer task stimuli.

<u>Treatment 11</u> refers to factorial combination $A_3B_2C_1$. The group receiving this treatment was given relevant label pretraining on low form stimuli, and performed the transfer task with the same stimuli. The pretraining labels were also relevant to the transfer stimuli.

<u>Treatment 12</u> refers to factorial combination $A_3B_2C_2$. The group receiving this treatment was given relevant label pretraining on high form level stimuli, and performed the transfer task with the same stimuli. The pretraining labels were also relevant to the transfer stimuli.

The method of the study and the orthogonal arrangement of experimental conditions, with tenable assumptions, provided for statistical analysis as an $A_3B_2C_2D_2E_2S_2^{96}$ fixed effects factorial design. The letter designation of each factor and the number of levels of each factor are indicated by the summary notation of the design. The subscript and superscript of the S term of the design notation indicate, respectively, the number of replications (2 <u>Ss</u>) at each factorial combination, and the total number of replications (96 Ss) over the total number of factorial combinations (48).

An analysis of variance, assuming a fixed effects model with interaction, was planned as the first step in the treatment of the data. This analysis provides relatively direct information concerning whether the pretraining effect was a function of the form level of the stimuli, a function of S's age, and/or a function of S's IQ score (factors C, D, and E).

The analysis of variance does not provide as directly interpretable information for factors A and B, nor for interactions containing these factors. Since interaction effects among factors A, B, and C were anticipated, several sets of orthogonal comparisons between the components of these effects were planned. Comparisons were planned among the types of pretraining (overall simple effects of levels of factor A) to test whether pretraining was superior to no pretraining, and relevant label pretraining was superior to irrelevant label pretraining. Comparisons were planned between types of pretraining within levels of factors B and C to test components of the simple effects of factor A. Comparisons of the two types of stimulus relationships (levels of factor B), within levels of factors A and C were planned to test whether relevant stimulus pretraining was superior to irrelevant stimulus pretraining.

Comparisons between the combinations of the levels of factors A and B, within levels of factor C, were planned to investigate whether the pretraining effect was a function of the relevance of the pretraining stimuli to the transfer task stimuli, a function of the relevance of the pretraining labels to the pretraining stimuli, a function of the relevance of the pretraining labels to the transfer task stimuli, and/or combinations of these functions.

Ordinal relationships among treatment conditions that would result from various combinations of functions of pretraining were made prior to running the experiment. For example, if the pretraining effect were a function only of having the same stimuli in the pretraining and transfer stages, there would not be differences among Treatments 11 and 12 and Treatments 5 and 6, but these treatments would produce fewer errors than Treatments 7, 8, 9, and 10. For complete outline of experimental treatments see Table V (Procedure Section).

Apparatus and Materials

The stimuli were twenty visual forms projected onto a screen. Figure 1 presents the twenty stimulus forms grouped according to alternate lists within form levels. The stimuli were constructed and selected following the method of Pfafflin (1960).[2] Pfafflin's forms were drawn as accurately as possible on an enlarged scale using a ruler, straight edge, and a compass. Each form was reproduced on black construction paper and mounted in the center of a sheet of white construction paper. Six original forms were produced in a similar manner but were modeled after familiar objects such as a comb, a football, and a key.

The thirty-six mounted forms were processed into 35 mm slides by a local photography shop. The photographer was instructed to use a

2. Pfafflin sent the present author photographic reproductions of the stimulus forms she had used in her doctoral research.

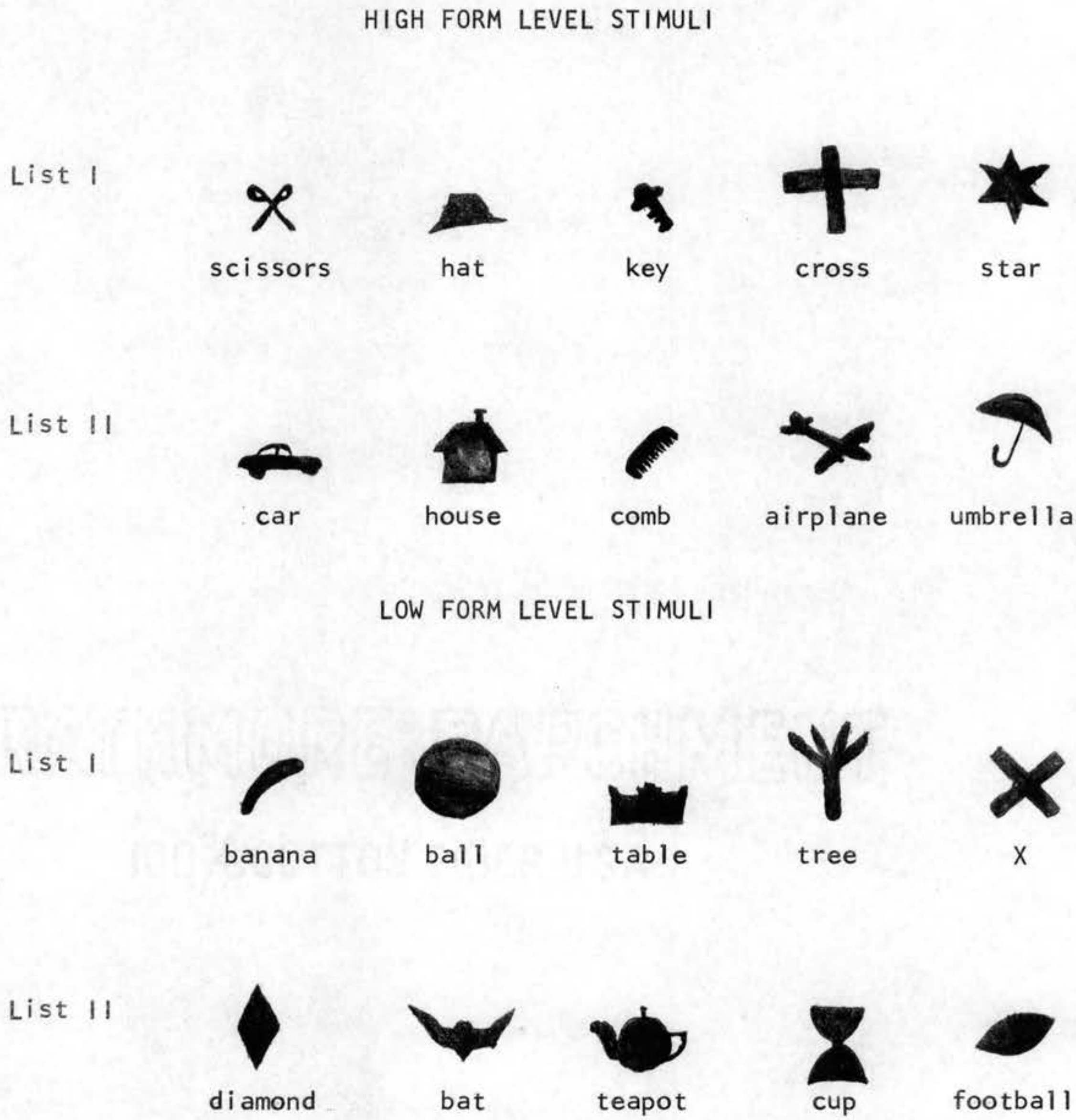


Figure 1. The twenty stimulus forms in the lists of five stimuli used in this experiment, grouped into form levels according to whether a high or a low percentage of the naming response to a form used the modal label.

fixed camera position, constant camera settings, constant lighting conditions, and fixed positions of mounted forms and equipment. Uniform materials and procedures were used in processing the film to obtain slides that differed only with respect to the stimulus forms.

The index of labeling consistency and the modal labels for each form were determined by the following method. Forty-eight children and adolescents were randomly selected from the institution population. These patients were taken one at a time to the experimental room and were seated at the table. The forms were successively projected onto the screen in a different randomized sequence for each patient. The patients were instructed to give each picture a name and were told, after the first presentation, that the name could be one they had used before or a new name. The entire sequence was repeated for four presentations. The naming responses were recorded verbatim. None of the experimental Ss served in the labeling procedure.

The 48 patients responded 4 times to each of the forms; thus, each form had a total of 192 naming responses given to it. The modal label for each form was determined by the most frequent name given it. The index of labeling consistency for each form was calculated by dividing the number of times the modal label had been the response, by the total number of responses.

The forms were ranked according to the obtained labeling consistency percentages. Ten forms with high labeling consistency percentages were selected for use in the experiment as the high form level stimuli, and 10 forms with intermediate labeling consistency percentages were selected for use in the experiment as the low form level stimuli. The ten stimuli of the high form level had a mean labeling consistency of 94.4%.

The ten stimuli of the low form level had a mean labeling consistency of 40.7%. The selection criteria were used to provide stimulus lists with mean consistencies approximating Pfafflin's corresponding form levels (94% and 48% respectively).

The modal label assigned by the patients to the stimulus, regardless of the actual frequency was considered to be the most appropriate or relevant label. Irrelevancy was achieved by exposing a given stimulus and attaching to it the label relevant to another stimulus in the same series. Figure 1, above, presents the 20 stimulus forms with their modal labels.

The stimuli were presented with a Kodak Carousel Projector, Model 550, at the low intensity setting. The projector and one 100 watt lamp provided the only illumination during the experimental sessions. The stimuli were projected onto a screen made of a rigid flat surface coated with four coats of flat-white paint. The screen and projector were angled to project a rectangular lighted frame around the stimulus form. The projector was approximately three feet to the right of the subject. The projected forms were approximately nine feet from the S. The centers of the projected forms were approximately at eye level for the seated S. The positions of the screen, projector, manipulandum, table, and lamp were held constant. The focus adjustment was set so that the images appeared at maximum clarity to the assistant who operated the projector. A plywood partition between the S and the projector operator prevented the S from observing the projector slide rack and the switching apparatus.

The apparatus used in the transfer stage is described below. The unit, which was placed in front of the S, was a metal box 8 inches wide, 12 inches deep, and 2 inches high. Five buttons were mounted on top of the unit. The buttons were equally spaced along a straight line across the width of the unit. A signal light was mounted 4 inches ahead of the center button. The light was a 6 volt lamp and had a translucent white plastic cover. A 16 volt, 2 bar door chime, a 6 volt buzzer, and a transformer were mounted inside the metal box. This unit containing the response buttons and signal light was interconnected with a switching unit that was placed near the projector operator. This latter unit consisted of five toggle switches mounted in a straight line on a metal case 4 inches long, 2 inches deep, and 2 inches high. Each switch was connected with the button in the corresponding position on the other unit. When a switch was in the <u>up</u> position, the corresponding button was in an electrical circuit with the buzzer. When a switch was in the <u>down</u> position, the corresponding button was in an electrical circuit with the light and the door chime. The switching unit could be set so that the switch corresponding to the correct button was in the <u>down</u> position and the other four switches corresponding to the incorrect buttons were in the <u>up</u> position. With the apparatus set in this pattern, pressing the correct button activated the light and door chime, and pressing any of the incorrect buttons activated the buzzer. Pictures of the apparatus are presented in Appendix A.

## Procedure

The procedure was administered by two persons. One individual operated the projector and switching device. The other individual, designated as <u>E</u>, presented the instructions and recorded the responses.

The <u>E</u> and the projector operator had identical record sheets which contained prearranged randomized sequences for the order of presenting the stimuli of the pretraining trials and the motor response trials. A copy of the record sheet is provided in Appendix B.

The record sheets were identical for all Ss. The five stimulus slides were placed in the first five projector slots in a different random order for each S. The projector operator followed the random sequences by depressing the selector button on the projector, rotating the circular slide rack to the first digit of the first trial sequence, then the second digit, and so on. When the selector button was released, the stimulus appeared on the screen.

Subjects were divided into 12 groups as shown in Table V. Eight groups received pretraining and 4 groups received no pretraining.

Pretraining Procedure

Five stimulus slides were presented randomly to each subject. During the first five presentations, the E supplied a label for each stimulus. The S repeated this label. On subsequent trials the S only supplied the label. If S supplied an "incorrect" label, he was given a "correctional" trial in which E again gave him the original correct label. This procedure was continued until the S responded correctly for two complete presentations of stimuli. Criterion was thereby set at ten correct responses out of ten trials. Labels and stimuli were varied for each treatment group (see Table V).

Groups 1, 2, 3, and 4 received no pretraining. Groups 5, 7, 9, and 11 were presented the stimuli of low form level list II. Groups 6, 8, 10, and 12 were presented the stimuli of high form level List II. A copy of the instructions given to the Ss during pretraining is seen in Appendix C.

TABLE V

SUMMARY OF THE EXPERIMENTAL TREATMENTS

| Group | Treatment | Pretraining Type | Pretraining Stimulus List | | Pretraining Label List | | Transfer Stimulus List | |
|---|---|---|---|---|---|---|---|---|
| 1 | $A_1B_1C_1$ | None | - | | - | | Low | I |
| 2 | $A_1B_1C_2$ | None | - | | - | | High | I |
| 3 | $A_1B_2C_1$ | None | - | | - | | Low | II |
| 4 | $A_1B_2C_2$ | None | - | | - | | High | II |
| 5 | $A_2B_1C_1$ | Irrel | Low | II | Low | I | Low | I |
| 6 | $A_2B_1C_2$ | Irrel | High | II | High | I | High | I |
| 7 | $A_2B_2C_1$ | Irrel | Low | II | Low | I | Low | II |
| 8 | $A_2B_2C_2$ | Irrel | High | II | High | I | High | II |
| 9 | $A_3B_1C_1$ | Rel | Low | II | Low | II | Low | I |
| 10 | $A_3B_1C_2$ | Rel | High | II | High | II | High | I |
| 11 | $A_3B_2C_1$ | Rel | Low | II | Low | II | Low | II |
| 12 | $A_3B_2C_2$ | Rel | High | II | High | II | High | II |

Transfer Task Procedure

General procedures were the same for both pretraining and no pre-training groups. Treatment conditions were varied as listed in Table V.

The five stimulus slides for the transfer task condition to which the subject had been assigned, were randomized. The random order was different for each S. The randomized stimuli were placed in the first five projector slots according to the sequences of 5 digits listed on the record sheet. These sequences had been previously selected randomly according to a latin square technique. The 40 sequences were the same for all Ss.

The E demonstrated the task to each S for one complete presentation of the five stimuli. A copy of the instructions to S is presented in Appendix D.

Following the demonstration, the five stimuli were presented in a random sequence. The projector operator followed the sequence on the record sheet and set the switching apparatus so that when the "correct" button was pressed the light came on and the door chime sounded. When any of the four "incorrect" buttons were pressed, the buzzer sounded.

If S pushed more than one button per stimulus or did not look at the stimuli before choosing a button or pushed the same button several times in a row, the demonstration was repeated between the 5th and 6th trial. After each incorrect response, the E pressed the correct button and said, "This is the right button for that picture."

The transfer task was continued until either the S responded without error for five consecutive sequences, or until all 40 sequences on the record sheet were completed.

Record sheets were scored by circling the incorrect responses, and total number of errors per S was determined. Error scores for each S and analysis of variance applied.

CHAPTER IV

RESULTS

Analysis of the data was based on the number of errors per S to criterion on the transfer task. All Ss performed to a criterion of 5 perfect trials (a minimum of 25 out of 25 correct responses), or for 40 trials (200 responses), whichever came first. The obtained error scores per S are presented in Appendix E.

The frequency distribution of error scores was plotted and inspected (see Appendix F). In view of the apparent positive skewness of the distribution, a log transformation of the data was performed (Ray, 1960; Pp. 77-78). The transformation formula used was:

$$X_t = 10 \log (X_{rs} + 2)$$

where Xt is the transformed score and $X_{rs}$ is the raw score. Application of the Cochran test for homogeneity of variance to the transformed data indicated the tenability of the hypothesis of homogeneity of variance.

Table VI presents a summary of the analysis of variance on the transformed data. The table shows that the obtained F value for the main effect of factor E (verbal IQ level of subjects) exceeded statistical significance ($p < .01$). This finding indicated that the higher verbal IQ groups performed the transfer task with significantly fewer errors than the lower verbal IQ groups.

Table VI also shows that the analysis found no significant main effects for factors A, B, C, or D (Type of Pretraining, Type of Stimulus

TABLE VI

SUMMARY OF THE ANALYSIS OF VARIANCE ON THE

TRANSFORMED ERROR SCORES

| | Source of Variance | SS | df | MS | F |
|---|---|---|---|---|---|
| A | Pretraining Type (PT) | 29.316 | 2 | 14.658 | 1.550 |
| B | Identical vs Different Stimuli (ID) | 15.833 | 1 | 15.833 | 1.675 |
| C | Form Level | 16.692 | 1 | 16.692 | 1.765 |
| D | Chronological Age (CA) | 11.823 | 1 | 11.832 | 1.250 |
| E | Verbal IQ | 134.041 | 1 | 134.041 | 14.177** |
| AB | PT x ID | 58.548 | 2 | 29.274 | 3.096 |
| AC | PT x Form | 1.112 | 2 | .556 | -- |
| AD | PT x CA | 43.332 | 2 | 21.666 | 2.291 |
| AE | PT x IQ | 67.733 | 2 | 33.867 | 3.582* |
| BC | ID x Form | 56.591 | 1 | 56.591 | 5.985* |
| BD | ID x CA | 26.590 | 1 | 26.590 | 2.812 |
| BE | ID x IQ | 3.188 | 1 | 3.188 | -- |
| CD | Form x CA | 9.068 | 1 | 9.068 | -- |
| CE | Form x IQ | 11.416 | 1 | 11.416 | 1.207 |
| DE | CA x IQ | 1.832 | 1 | 1.832 | -- |
| ABC | PT x ID x Form | 6.330 | 2 | 3.165 | -- |
| ABD | PT x ID x CA | 18.451 | 2 | 9.225 | -- |
| ABE | PT x ID x IQ | 33.562 | 2 | 16.781 | 1.775 |
| ACD | PT x ID x CA | 116.317 | 2 | 58.158 | 6.151** |
| ACE | PT x Form x IQ | 52.869 | 2 | 26.434 | 2.796 |
| ADE | PT x CA x IQ | 17.265 | 2 | 8.633 | -- |
| BCD | ID x Form x CA | .043 | 1 | .043 | -- |
| BCE | ID x Form x IQ | 2.226 | 1 | 2.226 | -- |
| BDE | ID x CA x IQ | .114 | 1 | .114 | -- |
| CDE | Form x CA x IQ | 3.585 | 1 | 3.585 | -- |
| ABCD | PT x ID x Form x CA | 21.569 | 2 | 10.784 | 1.141 |
| ABCE | PT x ID x Form x IQ | 28.495 | 2 | 14.247 | 1.507 |
| ABDE | PT x ID x CA x IQ | 45.752 | 2 | 22.876 | 2.419 |
| ACDE | PT x Form x CA x IQ | 4.848 | 2 | 2.424 | -- |
| BCDE | ID x Form x CA x IQ | 47.773 | 1 | 47.773 | 5.053* |
| ABCDE | PT x ID x Form x CA x IQ | 6.504 | 2 | 3.252 | -- |
| Error Within Cells | | 453.842 | 48 | 9.455 | |
| | Total | 1346.658 | 95 | | |

*p = < .05 **p = < .01

Relationship, Form Level of Stimuli, and Age Level of Subjects, respectively).

Table VI further shows that the obtained F values for the first order interaction effects between factors A and E, and between factors B and C exceeded statistical significance ($p < .05$). The obtained F values for the second order interaction effect among factors A, C, and D exceeded statistical significance ($p < .01$). The obtained F value for the third order interaction effect among factors B, C, D, and E exceeded statistical significance ($p < .05$). Additional analyses of these interaction effects are described below. No other interaction effects were statistically significant.

The obtained F value for the first order interaction between factors A and B approached but did not reach statistical significance (See Table VI; obtained F value = 3.096; for $p < .05$ the critical F value = 3.19). Comparison of the simple effects of this interaction was planned before the data was obtained. The F test associated with individual components of variation was applied (Steel & Torrie, 1960, p. 203; Winer, 1962, p. 85). The obtained F value (see Table VII) associated with factor B (Type of Stimulus Relationship) within the No Pretraining Level of factor A, exceeded statistical significance ($p < .01$). The obtained F value associated with the comparison of both types of label pretraining versus no pretraining exceeded statistical significance ($p < .05$). Each of the two sets of comparisons shown in Table VII are orthogonal; however, they are not independent of each other.

TABLE VII

EXAMINATION OF THE INTERACTION BETWEEN TYPE OF PRETRAINING AND TYPE OF STIMULUS RELATIONSHIP

| Treatment Comparisons | df | | |
|---|---|---|---|
| Between Type of Stimulus Relationship | | | |
| Within no Pretraining | 1 | 72.63 | 7.68** |
| Within Irrelevant Label Pretraining | 1 | .12 | -- |
| Within Relevant Label Pretraining | 1 | 1.64 | -- |
| Between Pretraining and No Pretraining | | | |
| Within Different Stimuli | 1 | 45.87 | 4.85* |
| Within Identical Stimuli | 1 | 16.07 | 1.70 |
| Between Rel vs Irrel Label Pretraining | | | |
| Within Different Stimuli | 1 | 16.27 | 1.72 |
| Within Identical Stimuli | 1 | 9.65 | 1.02 |
| Error Within Cells | 48 | 9.46 | |

Examination of the interaction between factors A and E (Type of Pretraining by Verbal IQ Level of Subjects) by the Newman-Keuls method indicated that Ss with lower verbal IQ scores who were given either no pretraining or irrelevant label pretraining, made a significantly greater number of errors than similar Ss who were given relevant label pretraining. Ss with lower verbal IQ scores who were given no pretraining also made a significantly greater number of errors than Ss with higher verbal IQ scores, regardless of the type of pretraining given to the higher Ss. The computed values for the Newman-Keuls method can be seen in Appendix G-1.

Examination of the interaction among factors B and C (Type of Stimulus Relationship and Stimulus Form Level) by the Newman-Keuls method, among the pretraining groups indicated no differences. The Newman-Keuls, as performed on the group receiving no pretraining, indicated a statistically significant difference between number of errors on different lists of high form stimuli (See Appendix G-2).

Examination of the interaction among factors A, C, and D (Type of Pretraining, Stimulus Form Level, and Age Level) revealed no significant differences between the cell totals. The computed values for this examination are also shown in Appendix G-3.

The significant interaction among factors B, C, D, and E suggested the possibility of an atypical randomization. This possibility was checked by application of analysis of variance on the IQ scores over the treatment and CA conditions, and by application of analysis of variance on the CA's in months over the treatment and IQ score conditions. No statistically significant F values were obtained as can be seen in the summaries of these analyses in Appendix H and I, respectively.

The significance of these findings in terms of the objectives for which this study was designed, are discussed in the following chapter.

CHAPTER V

# DISCUSSION

Perhaps the most important finding of this study is that the PD phenomenon is present in the mentally retarded. This finding agrees with those of Cantor and Hottel (1957) and Smith and Means (1963). The phenomenon is interpreted in this study as a transfer phenomenon. According to Vanderplas (1958) PD studies examine transfer processes when stimulus properties and intralist relationship have been learned prior to the experimental condition. These criteria were met in this study. Pfafflin's (1960) work, on which the present study was modeled, used transfer of learning as one of the main investigatory factors.

The present study found a significant interaction between form level of the stimuli and the type of stimulus relationship. Examination of this effect by the Newman-Keuls method indicated no statistically significant differences for the pretraining groups, but did indicate that groups receiving no pretraining made a significantly different number of errors on different lists of high form stimuli. This finding seems to indicate that the meaningfulness of stimuli to retarded subjects is not fully reflected by Pfafflin's method of selecting according to labeling consistency. The retarded subjects who were not given pretraining, responded in an uneven or spotty pattern to stimuli selected in this manner, but subjects given pretraining responded in a more uniform manner, regardless of the relevancy of the labels or the particular stimuli of the form classes. Thus, pretraining seems to equalize meaningfulness of stimuli to groups of retarded subjects.

Pfafflin's measure of meaningfulness was reflected in the form level of the stimuli selected. In the present study form level alone had no influence on the transfer task performance. This finding seems to indicate that meaningfulness of the stimuli to retarded subjects may be more closely related to verbal IQ level than to form level as Pfafflin defined it.

The presence of the PD phenomenon is not uniform throughout the mentally retarded population used in this study. Statistical findings indicated that higher IQ subjects made significantly fewer errors on the transfer task than lower IQ subjects. A statistically significant interaction between verbal IQ levels of subjects and the types of pretraining conditions was also found. Further statistical examination of this interaction indicated that lower IQ subjects who received relevant label pretraining made significantly fewer errors on the transfer task than those lower IQ subjects who received no pretraining. Subjects at this same IQ level who received irrelevant label pretraining made fewer errors than the low IQ groups that received no pretraining, but made more errors than the lower IQ groups that received relevant label pretraining. However, these differences were not statistically significant. Thus the positive transfer appeared to be a function of the relevancy of the pretraining labels.

Comparisons among the higher IQ groups did not show a positive transfer effect from stimulus pretraining. The higher IQ groups that were given no pretraining made fewer errors than higher IQ groups that were given irrelevant label pretraining. These latter groups made fewer errors than the higher IQ groups that were given relevant label pretraining. These differences were not statistically significant by themselves, but suggest a trend.

These findings are interpreted as pointing to a relationship similar to one indicated by Pfafflin (1960). She interpreted the results of her study with college student subjects to indicate a relationship between the meaningfulness of the stimuli, the meaningfulness of pretraining labels, and the effect of stimulus pretraining. The present study, using the same kind of experimental methods and materials but with mentally retarded children and adolescents, obtained a pattern of findings in which interaction between relevant label pretraining and form level of stimuli may reflect a similar process.

Relevant label pretraining appears to facilitate subsequent discrimination, with either identical or similar stimuli of the same form level, when the meaningfulness of the stimuli to the subject is at a low level. The facilitation does not appear to occur when the meaningfulness of the stimuli to the subjects is already at a high level.

The finding that relevant label pretraining facilitated learning by the lower IQ subjects seems to support the view expressed by Pfafflin, that for stimuli low in meaning, relevant labels suggest appropriate categories, thus making it easier for subjects to associate distinctive features of the stimuli with features of a subsequent task. The present study, however, seems to point to a different relationship in which meaning is related to different levels and patterns of previous learning as reflected by verbal IQ scores. Viewed in this manner, the results of this study can be seen to be similar to those of Weir and

Stevenson (1959) in which age levels of children appeared to be related to the meaning and the transfer effect of pretraining.

## CHAPTER VI

## SUMMARY AND CONCLUSIONS

The object of this study was to examine the stimulus predifferentiation phenomenon (PD) in a mentally retarded population. The investigation was modeled after Pfafflin's (1960) study. The dimensions explored by both studies were relevancy of pretraining labels and form level of stimuli. Sets of ten high and ten low form level stimuli were selected according to the consistency with which an independent sample of subjects gave the same label for a stimulus when asked to name it. Relevant and irrelevant labels were attached to each stimulus in the two form levels. Subjects were divided randomly into groups that were given no pretraining, or pretraining with the labels.

Ninety-six subjects, drawn from four classifications of institutionalized, mentally retarded children and adolescents (ages 11-6 to 20-6, verbal IQ's 50 to 84), were divided into twelve groups of eight subjects each.

The transfer task was a motor discrimination task, in which subjects learned to press one of five buttons in response to each of the five stimuli in their form level group. The transfer task was continued, either until the subject responded without error for five consecutive sequences of the stimulus list, or until forty sequences were completed. The design was a 3x2x2x2x2 factorial design. Error scores per subject were determined and an analysis of variance applied. Newman-Keuls was computed to further test stimulus relation factors.

The findings indicated that the higher verbal IQ subjects made significantly fewer errors than the lower Verbal IQ subjects. A statistically significant interaction between type of pretraining and verbal IQ level was found. This interaction indicated that lower IQ subjects who were given relevant label pretraining made significantly fewer errors than subjects of the same IQ level who received no pretraining. Statistically significant interaction effects were found: (a) between stimulus relationship and form level; (b) between type of pretraining, form level, and age level; and (c) between stimulus relationship, form level, age level, and verbal IQ level. A comparison between types of pretraining within the stimulus relationship factor indicated a statistically significant difference between different stimulus lists at the no pretraining condition, but not in the pretraining groups.

The results of the study were interpreted as indicating that the PD phenomenon is present in the mentally retarded. The findings appeared to be in general agreement with the conclusion reached by Pfafflin (1960) when she indicated a relationship between meaningfulness of stimuli and meaningfulness of pretraining labels on the effect of stimulus pretraining. The present study pointed to a different relationship, however, in that meaning appeared to be related to the level of previous learning in particular subjects, as reflected by verbal IQ scores, chronological age, and form level. Of these three, IQ appeared to be the more decisive factor for mentally retarded subjects.

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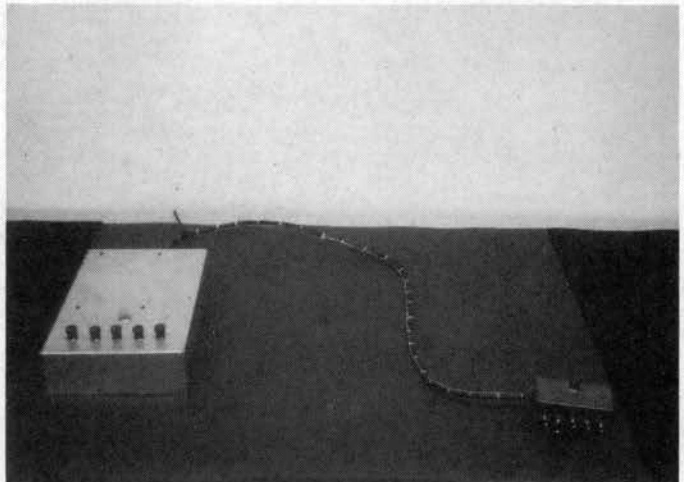
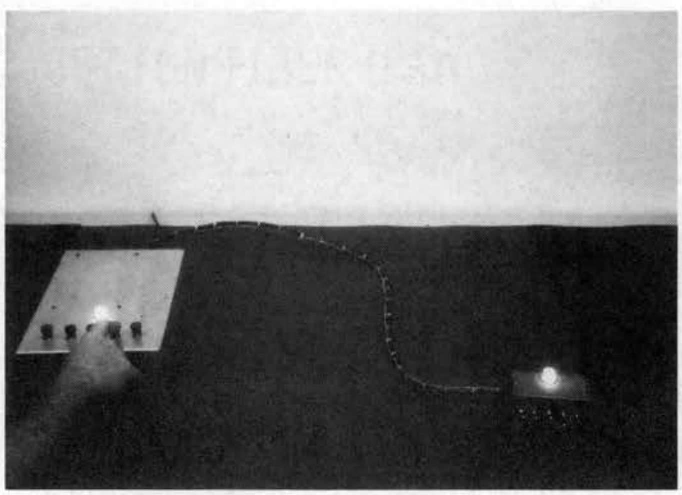
APPENDICES

# APPENDIX A



1. This photograph above shows the Transfer Task Apparatus and Switching Unit. Note the five buttons on the Transfer Apparatus and the five toggle switches on the Switching Unit which correspond in left right position.



2. The second photograph shows the Transfer Task Apparatus as a S would press one of the buttons. By careful inspection the viewer will note that button 4 is being pressed, switch 4 is in the down position, and the light (and door chime) are activated as they would be for a "correct" response.

# APPENDIX B

Projector # 1 2 3 4 5
Pretraining order 3 1 2 4 5
Transfer task order 5 1 4 2 3

Name____________________ Birthdate__________ Age_____ Sex_____

Date of Exp.Session______________ Hour______________ WAIS or WISC

Form Level: High Low

Treatment Group:
1 2 3 4 5 6 7 8 9 10 11 12

---

Pretraining Trials:

| | | | |
|---|---|---|---|
| 1. 2 1 4 3 5 | 5. 1 3 5 2 4 | 9. 2 3 1 4 5 | 13. 2 5 4 1 3 |
| 2. 5 4 2 1 3 | 6. 5 2 4 3 1 | 10. 1 4 3 5 2 | 14. 1 2 5 3 4 |
| 3. 3 5 1 4 2 | 7. 3 5 2 1 4 | 11. 5 1 3 4 2 | 15. 4 3 2 5 1 |
| 4. 4 2 3 5 1 | 8. 4 1 5 2 3 | 12. 3 4 1 2 5 | 16. 5 3 2 4 1 |

---

Discrimination Trials:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 4 | 2 | 3 | 1 | 5 | 21. | 1 | 5 | 2 | 3 | 4 |
| 2. | 2 | 1 | 5 | 3 | 4 | 22. | 5 | 2 | 3 | 4 | 1 |
| 3. | 3 | 4 | 1 | 5 | 2 | 23. | 2 | 1 | 4 | 5 | 3 |
| 4. | 5 | 3 | 4 | 2 | 1 | 24. | 3 | 4 | 1 | 2 | 5 |
| 5. | 1 | 5 | 2 | 4 | 3 | 25. | 4 | 3 | 5 | 1 | 2 |
| 6. | 5 | 3 | 2 | 1 | 4 | 26. | 3 | 4 | 5 | 2 | 1 |
| 7. | 2 | 5 | 3 | 4 | 1 | 27. | 1 | 5 | 2 | 3 | 4 |
| 8. | 4 | 2 | 1 | 3 | 5 | 28. | 2 | 3 | 4 | 1 | 5 |
| 9. | 3 | 1 | 4 | 5 | 2 | 29. | 5 | 2 | 1 | 4 | 3 |
| 10. | 1 | 4 | 5 | 2 | 3 | 30. | 4 | 1 | 3 | 5 | 2 |
| 11. | 5 | 3 | 4 | 2 | 1 | 31. | 5 | 2 | 4 | 1 | 3 |
| 12. | 1 | 4 | 3 | 5 | 2 | 32. | 3 | 1 | 2 | 5 | 4 |
| 13. | 3 | 1 | 2 | 4 | 5 | 33. | 1 | 4 | 5 | 3 | 2 |
| 14. | 4 | 2 | 5 | 1 | 3 | 34. | 2 | 3 | 1 | 4 | 5 |
| 15. | 2 | 5 | 1 | 3 | 4 | 35. | 4 | 5 | 3 | 2 | 1 |
| 16. | 1 | 4 | 5 | 2 | 3 | 36. | 5 | 3 | 1 | 2 | 4 |
| 17. | 5 | 3 | 2 | 1 | 4 | 37. | 3 | 4 | 2 | 5 | 1 |
| 18. | 2 | 5 | 3 | 4 | 1 | 38. | 2 | 1 | 4 | 3 | 5 |
| 19. | 3 | 1 | 4 | 5 | 2 | 39. | 4 | 2 | 5 | 1 | 3 |
| 20. | 4 | 2 | 1 | 3 | 5 | 40. | 1 | 5 | 3 | 4 | 2 |

# APPENDIX C

## INSTRUCTIONS GIVEN DURING PRETRAINING STAGE

The E presented the following instructions to the Ss in Groups 5, 6, 7, 8, 9, 10, 11, and 12, assigned to the pretraining conditions:

"This is some research to find out if saying different kinds of names for pictures helps boys and girls. First we are going to show you five pictures, one at a time. I will tell you the name we want you to say for the picture. I will say the name for the picture and then you say it right after me. Ready? Look at the picture." (The label for each picture as it appeared on the screen was spoken by the E and the S repeated the label.)

(Before the second trial the E said) "Now we will show the pictures again. I will say the name for the picture and then you say it right after me." (Before the 3rd, 4th, and 5th trials) "Ready?"

(Before the 6th trial and all subsequent test trials that followed a nontest trial, E said) "Now this time you say the names for the pictures by yourself."

(Before all subsequent test trials that followed a test trial E said) "Very good! Now we will do it that way again."

(Before all correction trials E said) "This time I will say the name for the picture, and you say it right after me."

(After two consecutive test trials with no errors E said) "Fine! Now we are ready to do something a little different."

# APPENDIX D

## INSTRUCTIONS GIVEN DURING TRANSFER TASK

The E presented the following instructions to all Ss during the transfer task:

"We are going to show you five pictures, one at a time. You are to find out which button belongs with each picture. If you push the right button, the light will go on and you will hear the door chime." (Demonstrate by pushing button 1.) "If you push one of the wrong buttons, the buzzer will sound." (Demonstrate by pushing buttons 2, 3, 4, and 5.) "You are to find out which button is right for each picture, and try to make the door chime and light come on. I will show you the right buttons the first time." (The demonstration trial was presented in the random order in which the slides had been placed in the projector slots. E pushed the correct button as each stimulus appeared on the screen, and said,) "This is the right button for that picture. Every time that picture comes on, this is the right button."

(After the demonstration, E said,) "Ready? Look at the pictures."

## APPENDIX E

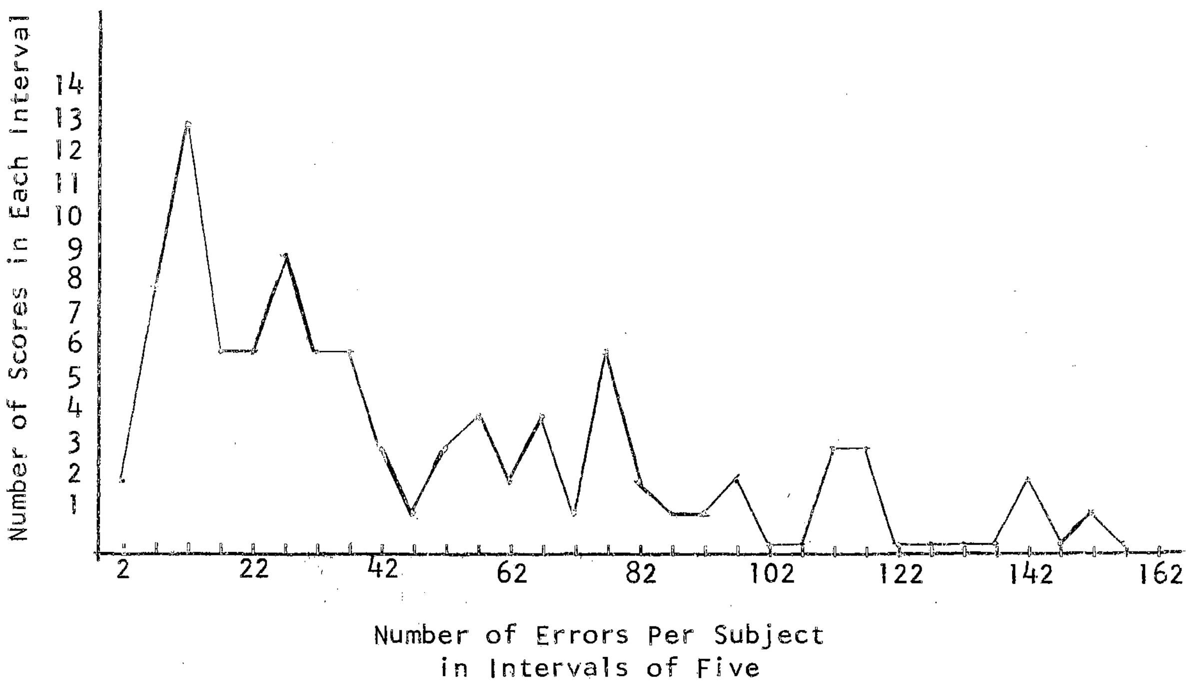
### ERRORS PER SUBJECT ON THE TRANSFER TASK ARRANGED BY SUBJECT AND TREATMENT CLASSIFICATIONS

| | | | $D_1$ | | $D_2$ | |
|---|---|---|---|---|---|---|
| | | | $E_1$ | $E_2$ | $E_1$ | $E_2$ |
| $A_1$ | $B_1$ | $C_1$ | 66 | 67 | 79 | 19 |
| | | | 52 | 40 | 118 | 13 |
| | | $C_2$ | 75 | 33 | 117 | 32 |
| | | | 83 | 13 | 112 | 36 |
| | $B_2$ | $C_1$ | 140 | 29 | 39 | 10 |
| | | | 57 | 6 | 15 | 78 |
| | | $C_2$ | 16 | 0 | 70 | 29 |
| | | | 19 | 14 | 77 | 8 |
| $A_2$ | $B_1$ | $C_1$ | 31 | 155 | 95 | 63 |
| | | | 13 | 6 | 19 | 25 |
| | | $C_2$ | 78 | 22 | 6 | 28 |
| | | | 118 | 81 | 38 | 30 |
| | $B_2$ | $C_1$ | 45 | 27 | 111 | 33 |
| | | | 140 | 13 | 59 | 26 |
| | | $C_2$ | 79 | 30 | 13 | 14 |
| | | | 40 | 42 | 57 | 13 |
| $A_3$ | $B_1$ | $C_1$ | 50 | 14 | 63 | 5 |
| | | | 68 | 27 | 16 | 4 |
| | | $C_2$ | 147 | 92 | 10 | 39 |
| | | | 12 | 35 | 8 | 21 |
| | $B_2$ | $C_1$ | 22 | 20 | 98 | 25 |
| | | | 21 | 67 | 88 | 57 |
| | | $C_2$ | 9 | 54 | 113 | 11 |
| | | | 24 | 36 | 28 | 9 |

A - Type of Pretraining
B - Type of Stimulus Relationship
C - Form Level of Stimuli
D - Age Level of Subjects
E - Verbal IQ Level of Subjects

APPENDIX F

FREQUENCY DISTRIBUTION OF ERROR SCORES



APPENDIX G - 1

EXAMINATION OF THE INTERACTION BETWEEN TYPE OF PRETRAINING AND VERBAL IQ LEVEL, BY THE NEWMAN-KEULS METHOD

| Treatment Cells<br>Pretraining<br>IQ Level | No<br>High | Rel.<br>High | Rel.<br>Low | Irrel.<br>High | Irrel.<br>Low | No<br>Low |
|---|---|---|---|---|---|---|
| Order | 1 | 2 | 3 | 4 | 5 | 6 |
| Cell Means | 13.23 | 14.17 | 14.82 | 14.86 | 16.65 | 17.87 |
| | | .94 | 1.59 | 1.63 | 3.42* | 4.64* |
| | | | .65 | .69 | 2.48 | 3.70* |
| | | | | .04 | 1.83 | 3.05* |
| | | | | | 1.79 | 3.01* |
| | | | | | | 1.22 |
| Critical Values ($q_r$ = .95) | | 2.20 | 2.64 | 2.91 | 3.11 | 3.25 |

APPENDIX G - 2

EXAMINATION OF THE INTERACTION BETWEEN TYPE OF STIMULUS RELATIONSHIP AND FORM LEVEL, BY THE NEWMAN-KEULS METHOD

Excluding Components from Groups Given No Pretraining

| Treatment Cells<br>Stimulus Relationship<br>Form Level | Identical<br>High | Different<br>Low | Different<br>High | Identical<br>Low |
|---|---|---|---|---|
| Order | 1 | 2 | 3 | 4 |
| Cell Means | 14.06 | 14.54 | 15.43 | 16.48 |
| | | .48 | 1.37 | 2.42 |
| | | | .89 | 1.94 |
| | | | | 1.05 |
| Critical Values ($q_r$ = .95) | | 2.20 | 2.64 | 2.91 |

Components from Groups Given No Pretraining

| Treatment Cells<br>Stimulus Relationship<br>Form Level | Identical<br>High | Identical<br>Low | Different<br>Low | Different<br>High |
|---|---|---|---|---|
| Order | 1 | 2 | 3 | 4 |
| Cell Means | 12.91 | 15.18 | 16.89 | 17.22 |
| | | 2.27 | 3.98* | 4.31* |
| | | | 1.71 | 2.04 |
| | | | | .33 |
| Critical Values ($q_r$ = .95) | | 3.10 | 3.73 | 4.12 |

## APPENDIX G - 3

### EXAMINATION OF THE INTERACTION BETWEEN TYPE OF PRETRAINING, FORM LEVEL, AND AGE LEVEL, BY THE NEWMAN-KEULS METHOD

| Treatment Cells | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pretraining | Rel. | No | Irrel. | Rel. | Rel. | Irrel. | No | Rel. | No | Irrel. | No | Irrel. |
| Form Level | High | High | High | Low | Low | Low | Low | High | Low | Low | High | High |
| Age Level | Older | Yngr. | Older | Older | Yngr. | Yngr. | Older | Yngr. | Yngr. | Older | Older | Yngr. |
| Order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Cell Means | 12.18 | 13.27 | 13.54 | 14.81 | 15.19 | 15.32 | 15.39 | 15.81 | 16.68 | 16.73 | 16.86 | 17.45 |
| | | 1.09 | 1.36 | 2.63 | 3.01 | 3.14 | 3.21 | 3.63 | 4.50 | 4.55 | 4.68 | 5.27 |
| | | | .27 | 1.54 | 1.92 | 2.05 | 2.12 | 2.54 | 3.41 | 3.46 | 3.59 | 4.18 |
| | | | | 1.27 | 1.65 | 1.78 | 1.85 | 2.27 | 3.14 | 3.19 | 3.32 | 3.91 |
| | | | | | .38 | .51 | .58 | 1.00 | 1.87 | 1.92 | 2.05 | 2.64 |
| | | | | | | .13 | .20 | .62 | 1.49 | 1.54 | 1.67 | 2.26 |
| | | | | | | | .07 | .49 | 1.36 | 1.41 | 1.54 | 2.13 |
| | | | | | | | | .42 | 1.29 | 1.34 | 1.47 | 2.06 |
| | | | | | | | | | .87 | .92 | 1.05 | 1.64 |
| | | | | | | | | | | .05 | .18 | .77 |
| | | | | | | | | | | | .13 | .72 |
| | | | | | | | | | | | | .59 |
| Critical Values ($q_r$ = .95) | | 3.11 | 3.74 | 4.12 | 4.39 | 4.60 | 4.77 | 4.91 | 5.03 | 5.15 | 5.24 | 5.34 |

# APPENDIX H

## SUMMARY OF THE ANALYSIS OF VARIANCE ON THE SUBJECTS' CHRONOLOGICAL AGE IN MONTHS

| | Source of Variance | SS | df | MS | F |
|---|---|---|---|---|---|
| A | Type of Pretraining (PT) | 51.813 | 2 | 25.906 | -- |
| B | Identical vs Different Stimuli (ID) | 71.760 | 1 | 71.760 | -- |
| C | Form Level | 49.594 | 1 | 49.594 | -- |
| E | Verbal IQ Level | 219.010 | 1 | 219.010 | -- |
| AB | PT x ID | 1054.146 | 2 | 527.073 | -- |
| AC | PT x Form | 924.438 | 2 | 462.204 | -- |
| AE | PT x IQ | 225.396 | 2 | 112.698 | -- |
| BC | ID x Form | 102.094 | 1 | 102.094 | -- |
| BE | ID x IQ | 38.760 | 1 | 38.760 | -- |
| CE | Form x IQ | 195.510 | 1 | 195.510 | -- |
| ABC | PT x ID x Form | 528.938 | 2 | 264.469 | -- |
| ABE | PT x ID x IQ | 2225.146 | 2 | 1112.573 | -- |
| ACE | PT x Form x IQ | 875.271 | 2 | 437.635 | -- |
| BCE | ID x Form x IQ | 219.010 | 1 | 219.010 | -- |
| ABCE | PT x ID x Form x IQ | 1461.021 | 2 | 730.510 | -- |
| Error | Within Cells | 85700.750 | 72 | 1190.288 | |
| | Total | 93942.656 | 95 | | |

## APPENDIX I

### SUMMARY OF THE ANALYSIS OF VARIANCE ON THE SUBJECTS' VERBAL IQ SCORES

| Source of Variance | SS | df | MS | F |
|---|---|---|---|---|
| A Type of Pretraining (PT) | 38.146 | 2 | 19.073 | -- |
| B Identical vs Different Stimuli (ID) | .844 | 1 | .844 | -- |
| C Form Level | .010 | 1 | .010 | -- |
| D Chronological Age (CA) | 21.094 | 1 | 21.094 | -- |
| AB PT x ID | 37.313 | 2 | 18.656 | -- |
| AC PT x Form | 2.521 | 2 | 1.260 | -- |
| AD PT x CA | 36.062 | 2 | 18.031 | -- |
| BC ID x Form | 114.844 | 1 | 114.844 | 1.141 |
| BD ID x CA | 11.344 | 1 | 11.344 | -- |
| CD Form x CA | 8.760 | 1 | 8.760 | -- |
| ABC PT x ID x Form | .188 | 2 | .094 | -- |
| ABD PT x ID x CA | 37.563 | 2 | 18.781 | -- |
| ACD PT x Form x CA | 138.521 | 2 | 69.260 | -- |
| BCD ID x Form x CA | 38.760 | 1 | 38.760 | -- |
| ABCD PT x ID x Form x CA | 9.021 | 2 | 4.510 | -- |
| Error Within Cells | 7246.250 | 72 | 100.642 | |
| Total | 7741.240 | 95 | | |

VITA

Daniel E. Smith

Candidate for the Degree of

Doctor of Philosophy

Thesis: THE EFFECT OF STIMULUS PRETRAINING ON DISCRIMINATION LEARNING IN RETARDATES

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## APPENDIX B

## STEADY HEAT CONDUCTION IN A HOLLOW CYLINDER WITH CONSTANT HEAT GENERATION AND PRESCRIBED WALL TEMPERATURE

It has been shown in Appendix A that the tube wall thickness and the heat generation vary somewhat around the circumference of the tube. However, in order to solve the problem of steady state heat conduction through the tube wall several simplifying assumptions had to be made. Two solutions, both of which are approximate, are presented in this Appendix and the results of the two are compared.

### Solution 1

In this solution the following assumptions are made:

1. The curvature of the coil is neglected.
2. Heat generation and wall thickness are assumed constant. The maximum deviation of these two quantities from the average are 11.8 and 5.7 per cent, respectively, for the small coil; 5.7 and 2.8 per cent for the large coil. After the solution of the partial differential equation, the local values of heat generation and wall thickness at any angular position of the tube are the suitable values to use in calculating

the inside wall temperature and radial flux.

3. Longitudinal conduction is negligible.

4. The electrical resistivity and the thermal conductivity of the metal are assumed to be independent of temperature and unaffected by cold-working.*

Polar

The appropriate differential equation in cylindrical coordinates is

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2} + \frac{G}{k} = 0 \qquad \text{(B-1)}$$

The known temperature profile and the insulated surface on the outside of the tube are reflected in the following two boundary conditions

$$T = F(\phi) \quad \text{at} \quad r = r_o \qquad \text{(B-2)}$$

$$\frac{\partial T}{\partial r} = 0 \quad \text{at} \quad r = r_o \qquad \text{(B-3)}$$

The above equation (the Poisson equation) is transformed into the Laplace equation by the substitution

$$T = t - \frac{G}{4k} r^2$$

resulting in

$$\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial^2 t}{\partial \phi^2} = 0 \qquad \text{(B-4)}$$

Now assume a product solution of the form

$$t = R(r) \cdot \Phi(\phi) \qquad \text{(B-5)}$$

where R is a function of r and $\Phi$ a function of $\phi$ only.

The substitution of the assumed product solution in

---

* The coils were stress-relieved at 1400 $^{\circ}$F for 3 hours.

equation (B-4) results in

$$\Phi \frac{d^2 R}{dr^2} + \frac{1}{r} \frac{dR}{dr} \Phi + \frac{1}{r^2} R \frac{d^2 \Phi}{d\phi^2} = 0 \qquad \text{(B-6)}$$

or

$$\frac{r^2}{R} \frac{d^2 R}{dr^2} + \frac{r}{R} \frac{dR}{dr} = - \frac{1}{\Phi} \frac{d^2 \Phi}{d\phi^2} \qquad \text{(B-7)}$$

Since the two sides of equation (B-7) can vary independently and yet are to be equal to each other, they both must be equal to a constant—the same constant. Therefore,

$$\frac{r^2}{R} \frac{d^2 R}{dr^2} + \frac{r}{R} \frac{dR}{dr} = - \frac{1}{\Phi} \frac{d^2 \Phi}{d\phi^2} = n^2 \qquad \text{(B-8)}$$

where n is a constant to be determined later.

We now have two ordinary differential equations, namely

$$r^2 \frac{d^2 R}{dr^2} + r \frac{dR}{dr} - n^2 R = 0 \qquad \text{(B-9)}$$

$$\frac{d^2 \Phi}{d\phi^2} + n^2 \Phi = 0 \qquad \text{(B-10)}$$

The solution of equation (B-9) is obtained by setting $R = r^a$ whereby $a = \pm n$ and

$$R = c_1 r^n + c_2 r^{-n} \qquad n \neq 0 \qquad \text{(B-11)}$$

$$R = c_3 + c_4 \ln r \qquad n = 0. \qquad \text{(B-12)}$$

The solution of equation (B-10) is

$$\Phi = c_5 \cos n\phi + c_6 \sin n\phi \quad n \neq 0 \qquad \text{(B-13)}$$

$$\Phi = c_7 \phi + c_8 \qquad n = 0 \qquad \text{(B-14)}$$

Since t must have the same value at $\phi$ as at $\phi + 2\pi$, $c_7$ must be zero and n can take integral values only. Furthermore, we must consider all the solutions of the above form.

Thus

$$t = [c_3 + c_4 \ln r + \sum_{n=1}^{\infty} (c_1 r^n + c_2 r^{-n})] \cdot$$

$$[c_8 + \sum_{n=1}^{\infty} (c_5 \cos n\phi + c_6 \sin n\phi)] \qquad \text{(B-15)}$$

$$T = -\frac{G}{4k} r^2 + A_o + B_o \ln r + \sum_{n=1}^{\infty} (A_n r^n + B_n r^{-n}) \cos n\phi + \sum_{n=1}^{\infty} (C_n r^n + D_n r^{-n}) \sin n\phi \qquad \text{(B-16)}$$

$$\frac{\partial T}{\partial r} = -\frac{G}{2k} r + B_o r^{-1} + \sum_{n=1}^{\infty} (n A_n r^{n-1} - n B_n r^{-n-1}) \cos n\phi + \sum_{n=1}^{\infty} (n C_n r^{n-1} - n D_n r^{-n-1}) \sin n\phi \qquad \text{(B-17)}$$

We now apply the two boundary conditions to equations (B-16) and (B-17) to get

$$-\frac{G}{4k} r_o^2 + A_o + B_o \ln r_o + \sum_{n=1}^{\infty} (A_n r_o^n + B_n r_o^{-n}) \cos n\phi + \sum_{n=1}^{\infty} (C_n r_o^n + D_n r_o^{-n}) \sin \phi = F(\phi) \qquad \text{(B-18)}$$

$$-\frac{G}{2k} r_o + B_o r_o^{-1} + \sum_{n=1}^{\infty} (n A_n r_o^{n-1} - n B_n r_o^{-n-1}) \cos n\phi + \sum_{n=1}^{\infty} (n C_n r_o^{n-1} - n D_n r_o^{-n-1}) \sin n\phi = 0 \qquad \text{(B-19)}$$

We notice that the right hand side of each of the equations (B-18) and (B-19) is the Fourier expansion of the function on the left; therefore the coefficients are given by

$$- \frac{G}{4k} r_o^2 + A_o + B_o \ln r_o = \frac{1}{2\pi} \int_0^{2\pi} F(\phi)\, d\phi \qquad \text{(B-20)}$$

$$- \frac{G}{2k} r_o + B_o r_o^{-1} = 0 \qquad \text{(B-21)}$$

$$\left.\begin{aligned} A_n r_o^{n} + B_n r_o^{-n} &= \frac{1}{\pi} \int_0^{2\pi} F(\phi) \cos n\phi \, d\phi \\ C_n r_o^{n} + D_n r_o^{-n} &= \frac{1}{\pi} \int_0^{2\pi} F(\phi) \sin n\phi \, d\phi \\ nA_n r_o^{n-1} - nB_n r_o^{-n-1} &= 0 \\ nC_n r_o^{n-1} - nD_n r_o^{-n-1} &= 0 \end{aligned}\right\} n = 1, 2, 3, \cdots \qquad \text{(B-22)}$$

The systems of equations (B-20) to (B-22) must be solved simultaneously to obtain the constants $A_o$, $B_o$ and $A_n$, $B_n$, $C_n$, $D_n$ for each value of n. The evaluation of the constants proceeds routinely if $F(\phi)$ is expressed as a Fourier series of finite number of terms.

In the actual case of evaluating the constants it was felt that only two terms were justified to describe the temperature distribution of the tube surface, i.e.,

$$F(\phi) = a + b \sin\phi$$

where

$$a = \tfrac{1}{2} (T_{hot} + T_{cold}) \qquad \text{(B-23)}$$

$$b = \tfrac{1}{2} (T_{hot} - T_{cold})$$

and $\phi$ is measured from the top of the tube (Fig. B-1).

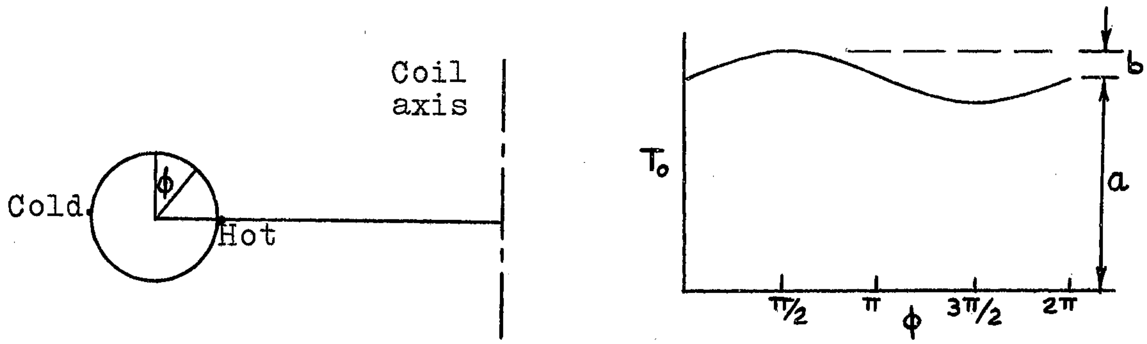


Fig. B1-a. Representation of Angular Position

Fig. B1-b. Assumed Temperature Profile on Outside of Tube

Fig. B-1. Diagramatic Representation of Temperature on the Outside of the Tube

With the above form of F ($\phi$) we get:

$$A_o = a + \frac{G}{4k} r_o^2 - \frac{G}{2k} r_o^2 \ln r_o$$

$$B_o = \frac{G}{2k} r_o 2$$

$$A_1 = 0$$

$$B_1 = 0$$

$$C_1 = \tfrac{1}{2} b\, r_o^{-1}$$

$$D_1 = \tfrac{1}{2} b\, r_o$$

All other coefficients in the equation (B-22) are zero.

Substituting these values of the constants in equations (B-16) and (B-17), we get

$$T = a + \frac{G}{4k} (r_o^2 - r^2) - \frac{G}{2k} r_o^2 \ln\left(\frac{r_o}{r}\right) + \frac{b}{2} \left(\frac{r}{r_o} + \frac{r_o}{r}\right) \sin\phi \qquad \text{(B-24)}$$

$$\frac{\partial T}{\partial r} = \frac{G}{2k} r_o \left( \frac{r_o}{r} - \frac{r}{r_o}\right) + \frac{b}{2r_o} \left(1 - \frac{r_o^2}{r^2}\right)\sin\phi \qquad \text{(B-25)}$$

The radial heat flux is given by

$$k \frac{\partial T}{\partial r} = \frac{G}{2} r_o \left( \frac{r_o}{r} - \frac{r}{r_o} \right) + \frac{bk}{2r_o} \left( 1 - \frac{r_o^2}{r^2} \right) \sin\phi \qquad \text{(B-26)}$$

The temperature drop through the wall is given by

$$T_o - T_i = \frac{G}{4k} r_o^2 \left[ \ln\left( \frac{r_o^2}{r_i^2} \right) + \frac{r_i^2}{r_o^2} - 1 \right]$$

$$+ \left[ 1 - \tfrac{1}{2} \left( \frac{r_i}{r_o} + \frac{r_o}{r_i} \right) \right] b \sin\phi . \qquad \text{(B-27)}$$

The circumferential temperature profile was generally of the form shown in Fig. B-1, i.e., point 2 was hot, point 4 cold, and points 1 and 3 had intermediate values. However, in the very high quality range points 1 and 3 were hot while 2 and 4 were cold. In this case the distribution was again assumed to be sinusoidal but with two maximum and two minimum points as shown in Fig. B-2.

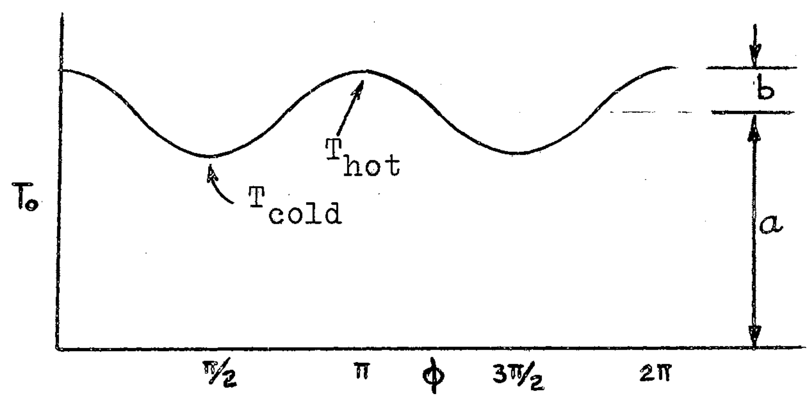


Fig. B-2. Diagrammatic Representation of Temperature on the Outside of Tube, High Quality Range

The temperature distribution here was taken as

$$T_o = a + b \cos 2\phi$$

Where $a = \frac{1}{2} (T_{hot} + T_{cold})$

$b = \frac{1}{2} (T_{hot} - T_{cold})$

Since the two cold points generally had different values, the arithmetic average of the two was used in evaluating a and b.

With the above form of circumferential temperature distribution the constants in equations (B-16) and (B-17) become

$$A_o = a + \frac{G}{4k} r_o^{\,2} - \frac{G}{2k} r_o^{\,2} \ln r_o$$

$$B_o = \frac{G}{2k} r_o^{\,2}$$

$$A_1,\ B_1,\ C_1,\ D_1 = 0$$

$$A_2 = \frac{b}{2} r_o^{-2}$$

$$B_2 = \frac{b}{2} r_o^{\,2}$$

The temperature at any point in the tube wall is given by

$$T = a + \frac{G}{4k}\left(r_o^{\,2} - r^2\right) - \frac{G}{2k} r_o^{\,2} \ln \frac{r_o}{r} + \frac{b}{2}\left(\frac{r^2}{r_o^{\,2}} + \frac{r_o^{\,2}}{r^2}\right) \cos 2\phi \qquad \text{(B-28)}$$

The radial heat flux is given by

$$k\frac{\partial T}{\partial r} = \frac{G}{2} r_o \left(\frac{r_o}{r} - \frac{r}{r_o}\right) + \frac{bk}{r_o}\left(\frac{r}{r_o} - \frac{r_o^{\,3}}{r^3}\right)\cos 2\phi \qquad \text{(B-29)}$$

Temperature drop through the wall is given by

$$T_o - T_i = -\frac{G}{4k}\left(r_o^{\,2} - r_i^{\,2}\right) + \frac{G}{2k} r_o^{\,2} \ln \frac{r_o}{r_i} - \frac{b}{2}\left(\frac{r_i^{\,2}}{r_o^{\,2}} + \frac{r_o^{\,2}}{r_i^{\,2}} - 2\right)\cos 2\phi \qquad \text{(B-30)}$$

If b = 0, the above equations reduce to the solution of conduction in a hollow cylinder with uniform heat generation and uniform outside wall temperature. The influence of the circumferential heat conduction on the radial heat flux and the temperature drop through the wall can be seen from equations (B-26) and (B-27), respectively. One interesting corollary is that, with the assumed circumferential temperature profile of $T_o = a + b \sin\phi$ on the outside of the tube, the radial heat flux and the temperature drop through the wall at $\phi = 0$ and at $\phi = \pi$ are not affected by the circumferential conduction. Of course, this will not be true in general for arbitrary forms of $F(\phi)$.

A more fundamental question is whether or not the knowledge of the temperature profile on the outside of the tube and the fact that it is insulated are sufficient to define the problem completely without knowing anything about the interior of the tube and the way in which heat is transferred to the fluid. The answer must be in the affirmative in as much as the conditions in the interior of the tube are reflected in the measured temperature profile on the outside; and, in a mathematical sense, two boundary conditions are sufficient to completely specify the problem at hand.

## Solution 2

In this solution, again, the tube is assumed to be straight and the dependence of thermal conductivity and electrical resistivity on temperature and cold-working are neglected. Let us consider a section of the tube wall as shown in Fig. B-3.

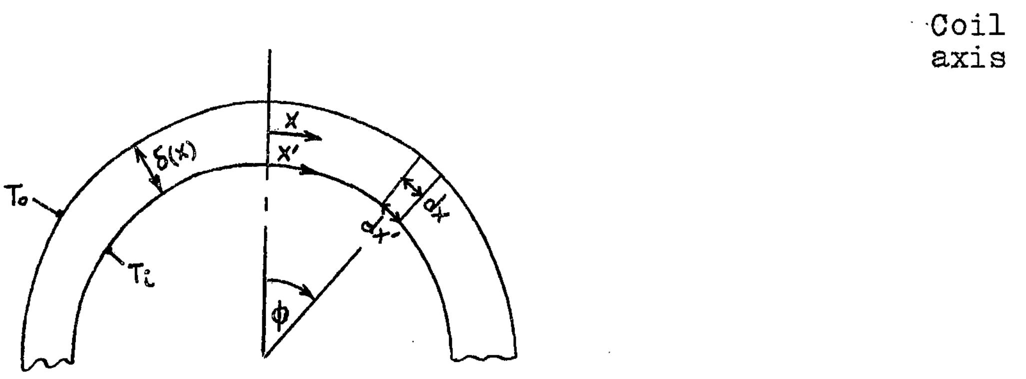


Figure B-3. Section of Tube Wall

Let x denote the distance measured along the mid-point of the wall and x' the distance along the inside surface. Let $\phi$ be the angle measured from the vertical line. Consider a volume element which has a thickness of $\delta$ , an average width of dx, and a depth of one foot. Let T(x) represent the temperature at the mid-point of the wall and, for the sake of simplicity, it will be assumed to be equal to the arithmetic average of the outside and the inside of the wall. This assumption is rather drastic, but the purpose of this solution is to provide us with an estimate of the influence of varying wall thickness and heat generation on the final answers.

The following energy terms, which are approximate, can be written:

heat generated = $G \; \delta_x \, dx$

heat conducted in = $- k \; \delta_x \left( \frac{\partial T}{\partial x} \right)_x$

$$\text{heat conducted out} = -k\ \delta_{x\,+\,dx}\left(\frac{\partial T}{\partial x}\right)_{x\,+\,dx}$$

$$= -k\left[\delta_x\left(\frac{\partial T}{\partial x}\right)_x + \frac{d\delta}{dx}\left(\frac{\partial T}{\partial x}\right)_x + \delta_x\left(\frac{\partial^2 T}{\partial x^2}\right)_x\right] dx$$

$$\text{heat convected out} = h\ (T_i - T_{sat})\ dx'$$

An energy balance yields

$$k\left[\frac{d\delta}{dx}\ \frac{dT}{dx} + \delta\,\frac{d^2\,T}{dx^2}\right] + G\delta = h\ (T_i - T_{sat})\frac{dx'}{dx} \qquad \text{(B-31)}$$

The circumferential variation of G and $\delta$ were derived in Appendix A, namely

$$G = G_m\left(\frac{R}{R - r_m\ \sin\phi}\right)^2$$

$$\delta = \delta_m\left(\frac{R}{R - r_m\ \sin\phi}\right).$$

Considering that

$$\frac{dx'}{dx} = \frac{r_i}{r_m}$$

and

$$\frac{d\delta}{dx} = \frac{d\delta}{d\phi}\ \frac{d\phi}{dx} = \frac{d\delta}{d\phi}\ \frac{1}{r_m}$$

equation (B-31) can be written in the following form

$$\frac{k}{r_m}\ \frac{d\delta}{d\phi}\ \frac{dT}{dx} + k\,\delta\,\frac{d^2\,T}{dx^2} + G\delta = h\ (T_i - T_{sat})\ \frac{r_i}{r_m} \qquad \text{(B-32)}$$

The first term of equation (B-32) represents the effect of a varying wall thickness, the second term is the net conduction, and the third is the heat generation term.

The inside wall temperature is related to the outside wall temperature from the solution of an insulated wall, i.e.,

$$T_i = T_o - \frac{G}{4k} r_o^2 \left[ \ln\left( \frac{r_o^2}{r_i^2} \right) + \frac{r_i^2}{r_o^2} - 1 \right] \qquad \text{(B-33)}$$

and

$$T = \tfrac{1}{2} (T_i + T_o)$$
$$= a + b \sin\phi - \frac{G}{8k} r_o^2 \left[ \ln\left( \frac{r_o}{r_o - \delta} \right)^2 + \frac{(r_o - \delta)^2}{r_o^2} - 1 \right] . \qquad \text{(B-34)}$$

$r_o$ is taken as constant while $\delta$ is allowed to be a function of $\phi$ . Now, the various terms in equation (B-32) can be written in terms of $\phi$ and known quantities as follows:

$$\frac{d\delta}{d\phi} = \delta_m R r_m (R - r_m \sin\phi)^{-2} \cos\phi \qquad \text{(B-35)}$$

$$\frac{dT}{dx} = \frac{dT}{d\phi} \frac{d\phi}{dx}$$
$$= \frac{b}{r_m} \cos\phi - \frac{G}{4k} r_o^2 \delta_m R \left( \frac{1}{r_o - \delta} - \frac{r_o - \delta}{r_o^2} \right)$$
$$(R - r_m \sin\phi)^{-2} \cos\phi \qquad \text{(B-36)}$$

$$\frac{d^2T}{dx^2} = \frac{d^2T}{d\phi^2} \left( \frac{d\phi}{dx} \right)^2$$

$$= - \frac{b}{r_m^2} \sin\phi - \frac{G}{4kr_m} r_o^2 \delta_m R \left[ \left( \frac{1}{(r_o - \delta)^2} + \frac{1}{r_o^2} \right) \right.$$
$$\frac{d\delta}{d\phi} (R - r_m \sin\phi)^{-2} \cos\phi \qquad \text{(B-37)}$$
$$+ 4\left( \frac{1}{r_o - \delta} - \frac{r_o - \delta}{r_o^2} \right) (R - r_m \sin\phi)^{-3} r_m \cos^2\phi$$
$$\left. - 2\left( \frac{1}{r_o - \delta} - \frac{r_o - \delta}{r_o^2} \right) (R - r_m \sin\phi)^{-2} \sin\phi \right] .$$

Numerical values were calculated for the position No. 91 for Run 14 for the small coil as follows:

$\phi = 0$

$b = 9.35\ ^{\circ}F$

$T_{sat} = 219.8\ ^{\circ}F$

$k = 9.32$ Btu/hr ft $^{\circ}F$

$G_m = 7.77 \times 10^{6}$ Btu/hr cu ft

$\delta_m = 5.69 \times 10^{-3}$ ft

$\delta = 5.69 \times 10^{-3}$ ft

$R = .410$ ft

$r_o = 2.62 \times 10^{-2}$ ft = .3144 x 2 = .6288 ($r_o$ in, OD in)

$r_m = 2.33 \times 10^{-2}$ ft = .2796 x 2 = .5592 in Dm

$r_i = 2.05 \times 10^{-2}$ ft = .246 x 2 = .492 (ID)

$\frac{d\delta}{d\phi} = 3.23 \times 10^{-4}$ ft/radian

$\frac{dT}{dx} = 364\ ^{\circ}F/ft$

$\frac{d^2T}{dx^2} = -288\ ^{\circ}F/ft^2$

$T_i = 233.4\ ^{\circ}F$

$\frac{k}{r_m} \frac{d\delta}{d\phi} \frac{dT}{dx} = 47.0$ Btu/(hr)(sq ft)

$k\,\delta \frac{d^2T}{dx^2} = -15.3$ Btu/(hr)(sq ft)  $G\delta = 44{,}200$ Btu/(hr)(sq ft)

The last three quantities demonstrate the insignificant effect of the varying wall thickness on the final result. The net conduction term is even more negligible; however, this is due to the choice of position around the circumference. The net circumferential conduction has its minimum at this point and its maximum at $\phi = \pi/2$ and $\phi = 3\pi/2$ . According to the first method, the net circumferential conduction is nil at this point (see Sample Calculations). $\frac{d\delta}{d\phi}$ has its maximum at this point but is nil at $\phi = \pi/2$ and $\phi = 3\pi/2$ .

The heat transfer coefficient calculated by this method is $h = 3{,}690$ Btu/(hr)(sq ft)($^{o}$F) compared to

$h = 3{,}717$ as calculated by the first method.

## APPENDIX C

## SAMPLE CALCULATIONS

The data were reduced on a digital computer. The following set of calculations, pertaining to position No. 63 for Run 14 of the small coil, is presented here to show how the calculations were made. The necessary data for subsequent calculations are reproduced here for convenience:

| | | |
|---|---|---|
| Water feed rate: | 78.5 lbs/hr | (Appendix E) |
| Current intensity: | 682 amps | (Appendix E) |
| Current potential: | 26.0 volts | (Appendix E) |
| Inlet temperature: | 217.0 °F | (Appendix E) |
| Thermocouple reading: | 1.290 millivolts | (Appendix E) |
| | ? .02 in App. | |
| Thermocouple correction: | 0.012 millivolts | (Appendix I) |
| Pressure at station No.6: | 18.73 psia | (Appendix G) |

The thermocouple correction was assumed to be due to the conduction of heat through the thermocouple wires and, thus, was proportional to the difference between the thermocouple junction temperature and the room temperature. The room temperature was 82 °F. Since the correction was measured when the coil surface temperature was at 212 °F, the correction at any other temperature was determined from

$$c = c_{212}\left(\frac{T_o - 82}{212 - 82}\right)$$

In the temperature range under consideration, the iron-constantan thermocouple generates an EMF of 0.0303 millivolts per 1 $^{o}$F temperature difference between its two junctions. Therefore, the corrected outside temperature was calculated from

$$T_o = \frac{c + EMF}{0.0303} + 212$$

$$= \frac{c_{212}\left(\frac{T_o - 82}{212 - 82}\right) + EMF}{0.0303} + 212$$

which can be rearranged to

$$T_o = \frac{c_{212} + EMF}{0.0303 - \frac{c_{212}}{130}} + 212$$

$$T_o = \frac{0.012 + 1.290}{0.0303 - \frac{0.012}{130}} + 212 = 255.1\ ^{o}F$$

1 watt = 3.413 Btu/hr

q' = 3.413 VI

= 3.413 x 26.0 x 682

= 60, 519 Btu/hr, total heat generated

Heat loss was 272 Btu/hr when the coil temperature was 212 $^{o}$F. Again, this loss was assumed to be proportional to the difference between the average coil temperature and the room temperature. The average coil temperature was based on the average of the four thermocouple Nos. 51, 52, 53, and 54.

Average coil temperature = 257 $^{o}$F

Heat loss = $q_{loss} = 272 \left(\frac{257 - 82}{212 - 82}\right) = 366$ Btu/hr

Net heat transferred to the boiling fluid:

$$q = 60519 - 366 = 60153 \text{ Btu/hr}$$

Exit quality was calculated from

$$x_{out} = \left[(T_{in} - 212)\ c_p + \frac{q}{W}\right] / h_{fg}$$

$$= \left[(217 - 212)\ 1.01 + \frac{60153}{78.5}\right] / 970.5$$

$$= 0.794 \text{ fraction vapor.}$$

uncorrected later.

Average heat flux =

$$(q/A)_{ave} = \frac{60153}{1.192} = 50{,}407 \text{ Btu/(hr)(sq ft)},$$

based on inside surface area of the heated portion of the coil. Average heat generation per unit volume of metal:

$$G = \frac{q}{\text{volume}} = \frac{60153}{13.36 \times 10^{-3}} = 7.77 \times 10^{6} \text{ Btu/(hr)(cu ft)}.$$

Net heat generation at $\phi = 3\pi/2$ : $7.77 \times 10^{6}$ Btu/(hr)(cu ft), assumed to be equal to the average heat generation.

Thermal conductivity of Inconel 600 at 255.1 °F was obtained by linear interpolation of the values reported in Appendix D:

$$k = 9.37 \text{ Btu/hr Ft } ^{\circ}F$$

Temperature drop through the tube wall, from equation (B-27):

$$T_o - T_i = \frac{7.77 \times 10^{6}}{4 \times 9.37} \left(\frac{0.3145}{12}\right)^2 \left[\ln\left(\frac{0.3145}{0.2462}\right)^2 + \left(\frac{0.2462}{0.3145}\right)^2 - 1\right]$$

$$= 14.6 \ ^{\circ}F$$

Inside wall temperature:

$$T_i = 255.1 - 14.6 = 240.5 \ ^{\circ}F$$

Radial heat flux, from equation (B-26):

$$k \frac{\partial T}{\partial r} = \frac{7.77\ (10^{6})}{2} \left(\frac{0.3145}{12}\right)\left(\frac{0.3145}{0.2462} - \frac{0.2462}{0.3145}\right)$$

$$= 50{,}385 \text{ Btu/(hr)(sq ft)}$$

Notice that for this position the second term on the right hand side of equations (B-27) and (B-26) vanishes, while at $\phi = \pi/2$ we get

$$\left[1 - \tfrac{1}{2}\left(\frac{r_i}{r_o} + \frac{r_o}{r_i}\right)\right] b \sin\phi = \left[1 - \tfrac{1}{2}\left(\frac{0.2462}{0.3145} + \frac{0.3145}{0.2462}\right)\right] 10.6$$

$$= -0.32 \ {}^{\circ}F$$

and

$$\frac{bk}{2r_o}\left(1 - \frac{r_o^2}{r_i^2}\right)\sin\phi = \frac{10.6\ (9.37)}{2\ (0.3145/12)}\left[1 - \left(\frac{0.3145}{0.2462}\right)^2\right]$$

$$= -1192 \text{ Btu/(hr)(sq ft)},$$

which shows to what extent the circumferential temperature gradient affects the temperature drop through the tube wall and the radial heat flux.

The pressure was interpolated from a graph of the measured pressures at Stations 1, 3, 5, 7, and 9:

saturation pressure = 18.73 psia

The saturation temperature was calculated from the following equation which was derived from the Steam Tables(20):

$$T_{sat} = \frac{8884.87}{15.9095 - \ln P} - 460$$

$$= \frac{8884.87}{15.9095 - \ln 18.73} - 460$$

$$= 224.5 \ {}^{\circ}F$$

Difference between saturation temperature and the inside wall temperature:

$$\Delta T = T_i - T_{sat}$$

$$= 240.5 - 224.5 = 16.0 \ {}^{\circ}F$$

Local heat transfer coefficient:

$$h = \frac{q/A}{\Delta T} = \frac{50{,}385}{16.0} = 3163 \text{ Btu/(hr)(sq ft)(}^{o}\text{F)}$$

The heat of vaporization and the vapor density were calculated from the following equations which were derived from the Steam Tables:

$$h_{fg} = 970.5 - 0.66\,(T_{sat} - 212)$$
$$= 970.5 - 0.66\,(224.5 - 212)$$
$$= 963 \text{ Btu/lb}$$

$$\rho_v = 1.022\left[\frac{18P}{10.73\,(T_{sat} + 460)}\right]$$
$$= 1.022\left[\frac{18\,(18.7)}{10.73\,(224.5 + 460)}\right]$$
$$= .0382 \text{ lb}_m\text{/cu ft} \qquad .0482$$

The vapor quality was calculated from a heat balance:

$$x = \left(\frac{q}{W}\ \frac{l}{9.35} + c_p(T_{in} - T_{sat})\right)/h_{fg},$$

where l is the axial length from the inlet. The total heated axial length of tube is 9.35 ft.

$$x = \left(\frac{60153}{78.5}\ \frac{6.1}{9.35} + 217 - 224.5\right)/963$$
$$= 0.512 \text{ fraction vapor.}$$

It should be noted here that the first thermocouple station was 1.10 ft away from the entrance electrode, while the other stations were spaced 1.00 ft from each other.

The heat transfer coefficients for position Nos. 61, 62, and 64, calculated in the above manner, are 4406, 2661, and 6015 Btu/(hr)(sq ft)($^{o}$F), respectively. The circumferential average heat transfer coefficient is calculated from equation (A-8) which takes into account the stretching of the outer wall and the shortening of the inner wall.

$$\bar{h} = (4406 + .949\ (2661) + 3163 + 1.051\ (6015))/4$$

$$= 4104\ \text{Btu/(hr)(sq ft)}(^{\circ}\text{F})$$

The vapor velocity is based on the total cross-sectional area of the tube:

$$V = \frac{Wx}{3600\ A_f\ \rho_v} = \frac{78.5\ (0.512)}{3600\ (1.322 \times 10^{-3})\ 0.0469}$$

$$= 179.9\ \text{ft/sec.}$$

The radial acceleration is given by:

$$\frac{a}{g} = \frac{V^2}{32.2R} = \frac{(179.9)^2}{32.2\ (4.93/12)}$$

$$= 2452\ \text{g's.}$$

The physical properties of water and water vapor, based on values reported in Eckert and Drake (10), were calculated at the saturation temperature of 224.5 $^{\circ}$F from the following relationships.

$$\rho_l = 59.97 - \frac{0.96}{36}\ (T_{sat} - 212)$$

$$= 59.97 - \frac{0.96}{36}\ (224.5 - 212)$$

$$= 59.6\ \text{lb}_m\text{/cu ft}$$

$$\mu_v = \left[8.54 + \frac{.49}{36}\ (T_{sat} - 224)\right](10^{-6})\ 3600$$

$$= \left[8.54 + \frac{.49}{36}\ (224.5 - 224)\right](10^{-6})\ 3600$$

$$= 0.0308\ \text{lb}_m\text{/(ft)(hr)}$$

$$Pr = 1.74 - \frac{0.294}{36}\ (T_{sat} - 212)$$

$$= 1.74 - \frac{0.294}{36}\ (224.5 - 212)$$

$$= 1.64$$

$$k_l = 0.395 \text{ Btu/(hr)(ft)(}^{o}\text{F)}$$

$$C_{pl} = 1.01 \text{ Btu/(lb)(}^{o}\text{F)}$$

$$\sigma = \left[33.6 - \frac{2.2}{36}(T_{sat} - 212)\right](12)(10^{-5})$$

$$= \left[33.6 - \frac{2.2}{36}(224.5 - 212)\right](12)(10^{-5})$$

$$= 3.94 \times 10^{-3} \text{ lb}_f\text{/ft}$$

The liquid viscosity was calculated from the Bingham's formula (26), namely

$$\mu_l = 241.9 \left[2.1482\left(\frac{T_{sat} - 212}{1.8} + 91.565\right) + \left[8078.4 + \left(91.565 + \frac{T_{sat} - 212}{1.8}\right)^2\right]^{\frac{1}{2}} - 120\right]^{-1}$$

$$= 0.640 \text{ lb}_m\text{/ft hr}$$

The Lockhart-Martinelli parameter is calculated as

$$X_{tt} = \left(\frac{1-x}{x}\right)^{0.9}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\left(\frac{\mu_l}{\mu_v}\right)^{0.1}$$

$$= \left(\frac{1-0.512}{0.512}\right)^{0.9}\left(\frac{0.0469}{59.6}\right)^{0.5}\left(\frac{0.640}{0.0308}\right)^{0.1}$$

$$= 0.0364$$

$$\frac{1}{X_{tt}} = 27.4$$

The circumferential average heat transfer coefficient if the liquid phase alone were flowing in the coil was calculated from equation (VI-4):

$$h_{lc} = 0.023 \text{ Re}^{0.85} \text{ Pr}^{0.4}\left(\frac{d}{D}\right)^{0.1} \frac{k_l}{d}$$

$$= 0.023 \left[\frac{(1-x)\,Wd}{\mu_l \, A_f}\right]^{0.85} \text{ Pr}^{0.4}\left(\frac{d}{D}\right)^{0.1}$$

$$= 0.023 \left[\frac{(1-0.512)(78.5)(0.4924/12)}{0.640\ (1.32)(10^{-3})}\right]^{0.85} (1.64)^{0.4} \left(\frac{0.4924}{9.86}\right)^{0.1}$$

$= 120$ Btu/hr sq ft $^{o}$F

$$\frac{\bar{h}}{\bar{h}_{lc}} = \frac{4104}{120}$$

$= 34.2$

# APPENDIX D

## PHYSICAL PROPERTIES OF INCONEL ALLOY 600*

### TABLE D-I

### THERMAL AND ELECTRICAL PROPERTIES OF ANNEALED INCONEL ALLOY 600

| Temperature, °F | Electrical Resistivity, ohms/circular mil/foot | Thermal Conductivity, Btu/hr ft °F | Specific Heat, Btu/lb °F |
|---|---|---|---|
| -250 | — | 7.17 | 0.073 |
| -200 | — | 7.42 | 0.079 |
| -100 | — | 7.75 | 0.090 |
| 70 | 620 | 8.58 | 0.106 |
| 200 | 625 | 9.08 | 0.111 |
| 400 | 634 | 10.1 | 0.116 |
| 600 | 644 | 11.1 | 0.121 |
| 800 | 657 | 12.1 | 0.126 |
| 1000 | 680 | 13.2 | 0.132 |
| 1200 | 680 | 14.3 | 0.140 |
| 1400 | 680 | 15.5 | 0.145 |
| 1600 | 686 | 16.7 | 0.149 |
| 1800 | 698 | — | — |
| 2000 | 704 | — | — |

* Reproduced from: Technical Bulletin T-7, "Engineering Properties of Inconel Alloy 600", Huntington Alloy Products Division, The International Nickel Co., Inc., Huntington, West Virginia 25720.

TABLE D-II

TENSILE AND CREEP PROPERTIES OF INCONEL 600*

| Temperature, °F | Tensile Strength, psi | Yield Strength, psi | Elongation, per cent | Stress for Creep Rate of 0.1% per 1000 Hours, psi |
|---|---|---|---|---|
| Room | 90,500 | 36,500 | 47 | — |
| 600 | 90,500 | 31,000 | 46 | — |
| 800 | 88,500 | 29,500 | 49 | 54,000 |
| 1000 | 84,000 | 28,500 | 47 | 25,000 |
| 1200 | 65,000 | 26,500 | 39 | 9,500 |
| 1400 | 27,500 | 17,000 | 46 | 3,600 |
| 1600 | 15,000 | 9,000 | 80 | 750 |
| 1800 | 7,500 | 4,000 | 118 | 560 |
| 2000 | — | — | — | 270 |
| 2100 | — | — | — | 170 |

* Hot-rolled at elevated temperatures.

## APPENDIX E

## HEAT TRANSFER DATA FOR SMALL COIL

### Run 3

### Saturated Boiling

| | |
|---|---|
| Water feed rate: | 77.2 lbs/hr |
| Current intensity: | 429 amps |
| Current potential: | 16.4 volts |
| Inlet pressure: | 1.00 psig |
| Inlet temperature: | 212.0 °F |
| Exit quality: | 31.6 per cent vapor |
| Average heat flux: | 19,600 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | .655 | .743 | .655 | .572 |
| 2 | .575 | .795 | .855 | .545 |
| 3 | .56 | .705 | .845 | .51 |
| 4 | .56 | .765 | .751 | .486 |
| 5 | .56 | .790 | .704 | .480 |
| 6 | .52 | .725 | .645 | .435 |
| 7 | .490 | .705 | .601 | .405 |
| 8 | .415 | .660 | .525 | .340 |
| 9 | .41 | .625 | .470 | .291 |

* Reference junction was in a steam bath open to the air.

## Run 4

### Saturated Boiling

| | |
|---|---|
| Water feed rate: | 77.3 lbs/hr |
| Current intensity: | 542 amps |
| Current potential: | 20.85 volts |
| Inlet pressure: | 2.07 psig |
| Inlet temperature: | 212.0 $^{o}$F |
| Exit quality: | 51.0 per cent vapor |
| Average heat flux: | 31,700 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.040 | 1.180 | .915 | .915 |
| 2 | 1.025 | 1.270 | 1.085 | .895 |
| 3 | 1.03 | 1.230 | 1.110 | .844 |
| 4 | .978 | 1.215 | .983 | .738 |
| 5 | .861 | 1.135 | .932 | .657 |
| 6 | .761 | 1.043 | .866 | .598 |
| 7 | .684 | .982 | .808 | .548 |
| 8 | .602 | .893 | .703 | .460 |
| 9 | .575 | .855 | .606 | .402 |

* Reference junction was in a steam bath open to the air.

Run 5

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 196.3 lbs/hr |
| Current intensity: | 865 amps |
| Current potential: | 33.0 volts |
| Inlet pressure: | 13.40 psig |
| Inlet temperature: | 221.8 $^{o}$F |
| Exit quality: | 51.9 per cent vapor |
| Average heat flux: | 80,400 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 2.548 | 2.605 | 2.285 | 2.280 |
| 2 | 2.683 | 2.785 | 2.590 | 2.325 |
| 3 | 2.538 | 2.823 | 2.464 | 2.140 |
| 4 | 2.360 | 2.718 | 2.262 | 1.920 |
| 5 | 2.155 | 2.530 | 2.173 | 1.762 |
| 6 | 1.976 | 2.325 | 2.060 | 1.670 |
| 7 | 1.825 | 2.170 | 1.951 | 1.567 |
| 8 | 1.638 | 2.003 | 1.740 | 1.375 |
| 9 | 1.458 | 1.800 | 1.485 | 1.173 |

* Reference junction was in a steam bath open to the air.

# Run 6

## Saturated Boiling

| | |
|---|---|
| Water feed rate: | 195.0 lbs/hr |
| Current intensity: | 688 amps |
| Current potential: | 26.25 volts |
| Inlet pressure: | 7.07 psig |
| Inlet temperature: | 210.7 °F |
| Exit quality: | 32.2 per cent vapor |
| Average heat flux: | 50,700 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.742 | 1.80 | 1.605 | 1.541 |
| 2 | 1.92 | 2.00 | 1.825 | 1.601 |
| 3 | 1.83 | 2.06 | 1.76 | 1.52 |
| 4 | 1.650 | 1.930 | 1.580 | 1.327 |
| 5 | 1.457 | 1.760 | 1.497 | 1.205 |
| 6 | 1.319 | 1.590 | 1.403 | 1.110 |
| 7 | 1.200 | 1.468 | 1.300 | 1.025 |
| 8 | 1.052 | 1.323 | 1.146 | .878 |
| 9 | .943 | 1.185 | .976 | .740 |

* Reference junction was in a steam bath open to the air.

Run 7

Saturated Boiling

Water feed rate: 121.2 lbs/hr

Current intensity: 544 amps

Current potential: 20.95 volts

Inlet pressure: 3.10 psig

Inlet temperature: 217.8 °F

Exit quality: 33.4 per cent vapor

Average heat flux: 31,900 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.10 | 1.284 | 1.132 | 1.056 |
| 2 | 1.10 | 1.326 | 1.228 | 1.000 |
| 3 | 1.08 | 1.346 | 1.185 | .949 |
| 4 | 1.062 | 1.295 | 1.032 | .821 |
| 5 | .925 | 1.169 | .965 | .728 |
| 6 | .816 | 1.044 | .893 | .663 |
| 7 | .742 | .975 | .832 | .612 |
| 8 | .644 | .883 | .721 | .513 |
| 9 | .600 | .810 | .625 | .434 |

* Reference junction was in a steam bath open to the air.

Run 8

Saturated Boiling

Water feed rate: 124.0 lbs/hr

Current intensity: 684 amps

Current potential: 26.05 volts

Inlet pressure: 5.62 psig

Inlet temperature: 216.0 °F

Exit quality: 50.6 per cent vapor

Average heat flux: 50,100 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longi- tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.69 | 1.808 | 1.545 | 1.570 |
| 2 | 1.80 | 1.912 | 1.695 | 1.495 |
| 3 | 1.63 | 1.875 | 1.62 | 1.356 |
| 4 | 1.501 | 1.795 | 1.450 | 1.178 |
| 5 | 1.329 | 1.645 | 1.374 | 1.059 |
| 6 | 1.190 | 1.494 | 1.284 | .972 |
| 7 | 1.085 | 1.385 | 1.195 | .904 |
| 8 | .950 | 1.260 | 1.052 | .770 |
| 9 | .861 | 1.150 | .886 | .660 |

*Reference junction was in a steam bath open to the air.

Run 14

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 78.5 lbs/hr |
| Current intensity: | 682 amps |
| Current potential: | 26.0 volts |
| Inlet pressure: | 5.00 psig |
| Inlet temperature: | 217.0 °F |
| Exit quality: | 79.5 per cent vapor |
| Average heat flux: | 49,800 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.62 | 1.825 | 1.545 | 1.56 |
| 2 | 1.69 | 1.895 | 1.59 | 1.45 |
| 3 | 1.60 | 1.800 | 1.60 | 1.31 |
| 4 | 1.45 | 1.800 | 1.445 | 1.13 |
| 5 | 1.30 | 1.680 | 1.38 | 1.00 |
| 6 | 1.15 | 1.575 | 1.29 | .925 |
| 7 | 1.08 | 1.505 | 1.20 | .875 |
| 8 | 1.00 | 1.400 | 1.10 | .785 |
| 9 | 1.10 | 1.375 | 1.25 | .745 |

* Reference junction was in a steam bath open to the air.

Run 16

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 124.5 lbs/hr |
| Current intensity: | 865 amps |
| Current potential: | 33.03 volts |
| Inlet pressure: | 11.83 psig |
| Inlet temperature: | 224.2 °F |
| Exit quality: | 81.6 per cent vapor |
| Average heat flux: | 80,400 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 2.450 | 2.60 | 2.579 | 2.275 |
| 2 | 2.532 | 2.700 | 2.488 | 2.225 |
| 3 | 2.370 | 2.775 | 2.375 | 2.050 |
| 4 | 2.245 | 2.658 | 2.200 | 1.815 |
| 5 | 2.068 | 2.485 | 2.115 | 1.690 |
| 6 | 1.88 | 2.315 | 2.00 | 1.600 |
| 7 | 1.76 | 2.215 | 1.91 | 1.543 |
| 8 | 1.615 | 2.080 | 1.78 | 1.382 |
| 9 | 1.59 | 1.980 | 1.67 | 1.270 |

* Reference junction was in a steam bath open to the air.

Run 18

Saturated Boiling

Water feed rate: 78.8 lbs/hr

Current intensity: 725 amps

Current potential: 27.6 volts

Inlet pressure: 6.04 psig

Inlet temperature: 212.3 °F

Exit quality: 88.9 per cent vapor

Average heat flux: 56,300 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.84 | 1.965 | 1.71 | 1.715 |
| 2 | 1.85 | 2.042 | 1.825 | 1.605 |
| 3 | 1.71 | 2.10 | 1.770 | 1.435 |
| 4 | 1.54 | 2.00 | 1.590 | 1.22 |
| 5 | 1.42 | 1.860 | 1.50 | 1.12 |
| 6 | 1.34 | 1.705 | 1.42 | 1.04 |
| 7 | 1.32 | 1.645 | 1.40 | 1.00 |
| 8 | 1.39 | 1.540 | 1.45 | +.015 |
| 9 | 1.95 | 1.57 | 1.89 | +.029 |

* Reference junction was in a steam bath open to the air.

# Run 19

## Saturated Boiling

| | |
|---|---|
| Water feed rate: | 78.1 lbs/hr |
| Current intensity: | 745 amps |
| Current potential: | 28.4 volts |
| Inlet pressure: | 6.50 psig |
| Inlet temperature: | 210.7 °F |
| Exit quality: | 94.6 per cent vapor |
| Average heat flux: | 59,500 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.92 | 2.08 | 1.78 | 1.815 |
| 2 | 1.93 | 2.16 | 1.915 | 1.675 |
| 3 | 1.74 | 2.19 | 1.84 | 1.50 |
| 4 | 1.60 | 2.08 | 1.66 | 1.29 |
| 5 | 1.47 | 1.95 | 1.58 | 1.17 |
| 6 | 1.39 | 1.815 | 1.46 | 1.09 |
| 7 | 1.37 | 1.73 | 1.52 | 1.08 |
| 8 | 1.55 | 1.65 | 1.82 | 1.07 |
| 9 | 4.85 | 1.87 | 5.80 | 1.95 |

*Reference junction was in a steam bath open to the air.

Run 20

Saturated Boiling

Water feed rate: 77.6 lbs/hr

Current intensity: 766.8 amps

Current potential: 29.4 volts

Inlet pressure: 7.36 psig

Inlet temperature: 214.3 $^{o}$F

Exit quality: 48 $^{o}$F superheated steam

Average heat flux: 63,400 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 2.10 | 2.24 | 1.93 | 1.95 |
| 2 | 2.10 | 2.30 | 2.15 | 1.81 |
| 3 | 1.90 | 2.31 | 2.00 | 1.63 |
| 4 | 1.78 | 2.26 | 1.80 | 1.40 |
| 5 | 1.67 | 2.13 | 1.71 | 1.30 |
| 6 | 1.62 | 2.00 | 4.55 | 1.33 |
| 7 | 1.88 | 1.93 | 1.87 | 1.30 |
| 8 | 4.48 | 2.00 | 4.55 | 1.33 |
| 9 | 11.85 | 4.92 | 9.50 | 4.67 |

* Reference junction was in a steam bath open to the air.

Run 21

Saturated Boiling

Water feed rate: 306 lbs/hr

Current intensity: 542 amps

Current potential: 20.85 volts

Inlet pressure: 5.27 psig

Inlet temperature: 226.2 °F

Exit quality: 14.3 per cent vapor

Average heat flux: 31,700 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 1.26 | 1.42 | 1.24 | 1.128 |
| 2 | 1.26 | 1.465 | 1.345 | 1.100 |
| 3 | 1.23 | 1.445 | 1.255 | 1.06 |
| 4 | 1.165 | 1.37 | 1.125 | .950 |
| 5 | 1.030 | 1.235 | 1.050 | .860 |
| 6 | .919 | 1.097 | .979 | .795 |
| 7 | .842 | 1.025 | .915 | .750 |
| 8 | .728 | .908 | .798 | .610 |
| 9 | .720 | .810 | .758 | .465 |

* Reference junction was in a steam bath open to the air.

Run 22

Single-Phase Water, Turbulent

Water feed rate: 329 lbs/hr

Current intensity: 279 amps

Current potential: 10.55 volts

Inlet pressure: ——

Inlet temperature: 108 °F

Exit quality: ——

Average heat flux: 32,500 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | −2.435 | −2.08 | −2.46 | −2.545 |
| 2 | −2.35 | −1.88 | −2.35 | −2.52 |
| 3 | −2.24 | −1.66 | −2.31 | −2.445 |
| 4 | −2.115 | −1.625 | −2.23 | −2.37 |
| 5 | −2.040 | −1.56 | −2.09 | −2.27 |
| 6 | −1.935 | −1.455 | −1.98 | −2.175 |
| 7 | −1.892 | −1.305 | −1.825 | −2.11 |
| 8 | −1.84 | −1.29 | −1.765 | −2.025 |
| 9 | −1.70 | −1.18 | −1.705 | −1.89 |

* Reference junction was in a steam bath open to the air.

# Run 24

## Subcooled Boiling

| | |
|---|---|
| Water feed rate: | 316 lbs/hr |
| Current intensity: | 560 amps |
| Current potential: | 21.5 volts |
| Inlet pressure: | —— |
| Inlet temperature: | 122.3 °F |
| Exit quality: | 4.0 per cent vapor |
| Average heat flux: | 33,700 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | .135 | 1.14 | -.145 | -.412 |
| 2 | .395 | 1.23 | .288 | -.282 |
| 3 | .65 | 1.53 | .470 | -.030 |
| 4 | .88 | 1.51 | .785 | .315 |
| 5 | .88 | 1.36 | 1.18 | .67 |
| 6 | .82 | 1.09 | 1.135 | .76 |
| 7 | .82 | 1.11 | 1.125 | .76 |
| 8 | .80 | 1.08 | 1.10 | .690 |
| 9 | .905 | 1.08 | 1.00 | .595 |

* Reference junction was in a steam bath open to the air.

Run 25

Single-Phase Water, Turbulent

| | |
|---|---|
| Water feed rate: | 354 lbs/hr |
| Current intensity: | 380 amps |
| Current potential: | 14.6 volts |
| Inlet pressure: | —— |
| Inlet temperature: | 128.8 °F |
| Exit quality: | —— |
| Average heat flux: | 15,500 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | -1.345 | -.81 | -1.43 | -1.56 |
| 2 | -1.185 | -.53 | -1.23 | -1.495 |
| 3 | -1.045 | -.200 | -1.15 | -1.385 |
| 4 | -.835 | -.140 | -.95 | -1.265 |
| 5 | -.72 | -.080 | -.76 | -1.10 |
| 6 | -.625 | +.080 | -.615 | -.935 |
| 7 | -.482 | +.255 | -.40 | -.755 |
| 8 | -.385 | +.285 | -.31 | -.615 |
| 9 | -.150 | +.450 | -.155 | -.455 |

* Reference junction was in a steam bath open to the air.

Run 26

Single-Phase Water, Laminar

| | |
|---|---|
| Water feed rate: | 94.8 lbs/hr |
| Current intensity: | 272 amps |
| Current potential: | 10.4 volts |
| Inlet pressure: | —— |
| Inlet temperature: | 104.2 $^{o}F$ |
| Exit quality: | —— |
| Average heat flux: | 7,800 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | -1.35 | -1.405 | -2.08 | -2.15 |
| 2 | -1.10 | -1.320 | -1.76 | -1.94 |
| 3 | -.710 | -.905 | -1.49 | -1.60 |
| 4 | -.375 | -.680 | -1.22 | -1.245 |
| 5 | -.065 | -.530 | -.845 | -.87 |
| 6 | .12 | -.160 | -.60 | -.56 |
| 7 | .255 | .16 | -.245 | -.24 |
| 8 | .12 | .16 | .02 | .025 |
| 9 | .13 | .18 | .21 | .07 |

* Reference junction was in a steam bath open to the air.

Run 27

Saturated Boiling

Water feed rate: 118.8 lbs/hr

Current intensity: 428 amps

Current potential: 16.4 volts

Inlet pressure: 1.39 psig

Inlet temperature: 214.8 °F

Exit quality: 20.8 per cent vapor

Average heat flux: 19,600 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | .59 | .82 | .87 | .620 |
| 2 | .55 | .875 | .865 | .590 |
| 3 | .56 | .75 | .865 | .55 |
| 4 | .585 | .795 | .755 | .515 |
| 5 | .563 | .798 | .683 | .478 |
| 6 | .530 | .715 | .620 | .445 |
| 7 | .495 | .69 | .580 | .425 |
| 8 | .425 | .595 | .500 | .325 |
| 9 | .448 | .565 | .495 | .215 |

* Reference junction was in a steam bath open to the air.

# Run 28

## Saturated Boiling

| | |
|---|---|
| Water feed rate: | 189.7 lbs/hr |
| Current intensity: | 425 amps |
| Current potential: | 16.25 volts |
| Inlet pressure: | 1.88 psig |
| Inlet temperature: | 216.3 °F |
| Exit quality: | 13.1 per cent vapor |
| Average heat flux: | 19,300 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | .65 | .835 | .795 | .633 |
| 2 | .65 | .875 | .875 | .610 |
| 3 | .65 | .80 | .845 | .610 |
| 4 | .655 | .825 | .750 | .552 |
| 5 | .616 | .80 | .680 | .50 |
| 6 | .565 | .715 | .622 | .465 |
| 7 | .521 | .67 | .580 | .440 |
| 8 | .440 | .585 | .495 | .343 |
| 9 | .452 | .540 | .485 | .231 |

* Reference junction was in a steam bath open to the air.

Run 29

Saturated Boiling

Water feed rate: 193.5 lbs/hr

Current intensity: 545 amps

Current potential: 20.95 volts

Inlet pressure: 4.09 psig

Inlet temperature: 223.4 °F

Exit quality: 21.7 per cent vapor

Average heat flux: 32,000 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longi- tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.19 | 1.430 | 1.261 | 1.125 |
| 2 | 1.20 | 1.366 | 1.212 | 1.07 |
| 3 | 1.18 | 1.423 | 1.225 | 1.015 |
| 4 | 1.110 | 1.326 | 1.071 | .883 |
| 5 | .975 | 1.192 | 1.000 | .785 |
| 6 | .861 | 1.05 | .927 | .719 |
| 7 | .796 | .994 | .875 | .683 |
| 8 | .685 | .875 | .756 | .545 |
| 9 | .685 | .779 | .715 | .388 |

* Reference junction was in a steam bath open to the air.

## APPENDIX F

## HEAT TRANSFER DATA FOR LARGE COIL

### Run 104

### Saturated Boiling

| | |
|---|---|
| Water feed rate: | 77.5 lbs/hr |
| Current intensity: | 545 amps |
| Current potential: | 21.3 volts |
| Inlet pressure: | 2.02 psig |
| Inlet temperature: | 209.3 °F |
| Exit quality: | 51.9 per cent vapor |
| Average heat flux: | 32,500 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | .91 | 1.065 | .995 | 1.020 |
| 2 | .88 | 1.185 | 1.045 | .990 |
| 3 | .85 | 1.085 | 1.04 | .88 |
| 4 | .80 | 1.13 | .952 | .79 |
| 5 | .83 | 1.07 | .872 | .727 |
| 6 | .70 | .960 | .759 | .645 |
| 7 | .70 | .864 | .699 | .552 |
| 8 | .60 | .826 | .633 | .495 |
| 9 | .54 | .742 | .575 | .415 |

* Reference junction was in a steam bath open to the air.

Run 105

Saturated Boiling

Water feed rate: 193.6 lbs/hr

Current intensity: 860 amps

Current potential: 32.45 volts

Inlet pressure: 12.63 psig

Inlet temperature: 222.8 $^{o}$F

Exit quality: 51.6 per cent vapor

Average heat flux: 78,600 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 2.262 | 2.382 | 2.295 | 2.270 |
| 2 | 2.445 | 2.515 | 2.333 | 2.272 |
| 3 | 2.360 | 2.515 | 2.310 | 2.152 |
| 4 | 2.160 | 2.440 | 2.140 | 1.952 |
| 5 | 2.150 | 2.328 | 2.026 | 1.858 |
| 6 | 1.910 | 2.165 | 1.862 | 1.718 |
| 7 | 1.833 | 1.995 | 1.755 | 1.573 |
| 8 | 1.601 | 1.848 | 1.586 | 1.396 |
| 9 | 1.398 | 1.613 | 1.390 | 1.193 |

* Reference junction was in a steam bath open to the air.

Run 106

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 194.0 lbs/hr |
| Current intensity: | 684 amps |
| Current potential: | 26.5 volts |
| Inlet pressure: | 6.91 psig |
| Inlet temperature | 212.2 °F |
| Exit quality: | 32.7 per cent vapor |
| Average heat flux: | 50,900 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.530 | 1.606 | 1.568 | 1.521 |
| 2 | 1.681 | 1.775 | 1.619 | 1.590 |
| 3 | 1.670 | 1.748 | 1.612 | 1.506 |
| 4 | 1.482 | 1.715 | 1.470 | 1.347 |
| 5 | 1.465 | 1.610 | 1.383 | 1.258 |
| 6 | 1.263 | 1.473 | 1.247 | 1.138 |
| 7 | 1.210 | 1.322 | 1.156 | 1.015 |
| 8 | 1.040 | 1.225 | 1.037 | .884 |
| 9 | .900 | 1.039 | .894 | .731 |

* Reference junction was in a steam bath open to the air.

Run 107

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 120.6 lbs/hr |
| Current intensity: | 544 amps |
| Current potential: | 21.25 volts |
| Inlet pressure: | 2.84 psig |
| Inlet temperature: | 216.6 $^{o}$F |
| Exit quality: | 33.9 per cent vapor |
| Average heat flux: | 32,400 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 1.02 | 1.125 | 1.052 | 1.06 |
| 2 | 1.06 | 1.265 | 1.083 | 1.04 |
| 3 | .99 | 1.175 | 1.070 | .962 |
| 4 | .923 | 1.180 | .973 | .852 |
| 5 | .930 | 1.075 | .900 | .786 |
| 6 | .770 | .965 | .789 | .700 |
| 7 | .750 | .862 | .725 | .617 |
| 8 | .640 | .815 | .655 | .538 |
| 9 | .565 | .712 | .579 | .444 |

* Reference junction was in a steam bath open to the air.

Run 108

Saturated Boiling

Water feed rate: 124.5 lbs/hr

Current intensity: 681 amps

Current potential: 26.4 volts

Inlet pressure: 5.21 psig

Inlet temperature: 215.6 °F

Exit quality: 50.8 per cent vapor

Average heat flux: 50,500 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 1.468 | 1.530 | 1.465 | 1.465 |
| 2 | 1.568 | 1.695 | 1.522 | 1.500 |
| 3 | 1.545 | 1.645 | 1.512 | 1.355 |
| 4 | 1.341 | 1.604 | 1.341 | 1.190 |
| 5 | 1.333 | 1.504 | 1.255 | 1.116 |
| 6 | 1.139 | 1.269 | 1.125 | 1.007 |
| 7 | 1.092 | 1.232 | 1.045 | .905 |
| 8 | .940 | 1.152 | .942 | .785 |
| 9 | .832 | .996 | .835 | .665 |

* Reference junction was in a steam bath open to the air.

Run 114

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 79.5 lbs/hr |
| Current intensity: | 685 amps |
| Current potential: | 26.5 volts |
| Inlet pressure: | 4.03 psig |
| Inlet temperature: | 211.8 $^{o}$F |
| Exit quality: | 79.8 per cent vapor |
| Average heat flux: | 51,000 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.40 | 1.475 | 1.395 | 1.432 |
| 2 | 1.45 | 1.635 | 1.476 | 1.430 |
| 3 | 1.41 | 1.575 | 1.451 | 1.267 |
| 4 | 1.22 | 1.555 | 1.287 | 1.095 |
| 5 | 1.23 | 1.482 | 1.195 | 1.005 |
| 6 | 1.05 | 1.361 | 1.05 | .905 |
| 7 | 1.03 | 1.240 | 1.00 | .81 |
| 8 | .95 | 1.185 | .95 | .73 |
| 9 | 1.6 | 1.085 | 1.09 | .73 |

* Reference junction was in a steam bath open to the air.

Run 116

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 126.2 lbs/hr |
| Current intensity: | 854 amps |
| Current potential: | 33.2 volts |
| Inlet pressure: | 9.83 psig |
| Inlet temperature: | 221.5 °F |
| Exit quality: | 79.6 per cent vapor |
| Average heat flux: | 79,800 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 2.137 | 2.218 | 2.131 | 2.11 |
| 2 | 2.283 | 2.355 | 2.165 | 2.12 |
| 3 | 2.183 | 2.337 | 2.140 | 1.945 |
| 4 | 1.975 | 2.273 | 1.972 | 1.755 |
| 5 | 1.975 | 2.172 | 1.850 | 1.665 |
| 6 | 1.740 | 2.027 | 1.695 | 1.536 |
| 7 | 1.675 | 1.895 | 1.598 | 1.412 |
| 8 | 1.47 | 1.781 | 1.46 | 1.268 |
| 9 | 1.38 | 1.615 | 1.41 | 1.123 |

* Reference junction was in a steam bath open to the air.

Run 119

Saturated Boiling

Water feed rate: 89.7 lbs/hr

Current intensity: 791 amps

Current potential: 30.65 volts

Inlet pressure: 7.10 psig

Inlet temperature: 225.3 °F

Exit quality: 96.0 per cent vapor

Average heat flux: 68,200 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.875 | 1.925 | 1.855 | 1.86 |
| 2 | 1.98 | 2.08 | 1.897 | 1.83 |
| 3 | 1.86 | 2.04 | 1.863 | 1.64 |
| 4 | 1.65 | 1.98 | 1.665 | 1.44 |
| 5 | 1.65 | 1.90 | 1.56 | 1.37 |
| 6 | 1.47 | 1.785 | 1.42 | 1.26 |
| 7 | 1.62 | 1.66 | 1.42 | 1.17 |
| 8 | 2.08 | 1.61 | 1.76 | 1.17 |
| 9 | 7.6 | 1.82 | 5.90 | 2.6 |

* Reference junction was in a steam bath open to the air.

Run 120

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 88.7 lbs/hr |
| Current intensity: | 812 amps |
| Current potential: | 31.5 volts |
| Inlet pressure: | 8.57 psig |
| Inlet temperature: | 225.5 °F |
| Exit quality: | 50 °F superheated steam |
| Average heat flux: | 72,000 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 2.01 | 2.06 | 1.99 | 1.99 |
| 2 | 2.13 | 2.21 | 2.02 | 1.97 |
| 3 | 2.00 | 2.19 | 2.01 | 1.80 |
| 4 | 1.80 | 2.13 | 1.81 | 1.60 |
| 5 | 1.80 | 2.06 | 1.70 | 1.50 |
| 6 | 1.62 | 1.95 | 1.61 | 1.40 |
| 7 | 2.02 | 1.84 | 1.71 | 1.36 |
| 8 | 6.50 | 1.93 | 4.05 | 1.70 |
| 9 | 11.85 | 4.75 | 9.40 | 4.22 |

* Reference junction was in a steam bath open to the air.

Run 124

Subcooled Boiling

| | |
|---|---|
| Water feed rate: | 308 lbs/hr |
| Current intensity: | 560 amps |
| Current potential: | 21.8 volts |
| Inlet pressure: | —— |
| Inlet temperature: | 119.7 °F |
| Exit quality: | 4.3 per cent vapor |
| Average heat flux: | 34,200 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | .340 | .64 | .07 | -.16 |
| 2 | .380 | .71 | .32 | .00 |
| 3 | .285 | .82 | .337 | .12 |
| 4 | .39 | 1.070 | .54 | .138 |
| 5 | .90 | 1.070 | .945 | .885 |
| 6 | .77 | .982 | .96 | .81 |
| 7 | .82 | .960 | .885 | .788 |
| 8 | .845 | .973 | .890 | .770 |
| 9 | .85 | .95 | .875 | .685 |

* Reference junction was in a steam bath open to the air.

Run 125

Single-Phase Turbulent

Water feed rate: 333 lbs/hr

Current intensity: 275 amps

Current potential: 10.65 volts

Inlet pressure: ——

Inlet temperature: 181.5 $^{o}F$

Exit quality: ——

Average heat flux: 8,000 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | -.357 | -.180 | -.413 | -.428 |
| 2 | -.276 | -.013 | -.297 | -.380 |
| 3 | -.215 | +.058 | -.228 | -.311 |
| 4 | -.143 | .165 | -.161 | -.235 |
| 5 | .023 | .251 | -.040 | -.122 |
| 6 | .028 | .305 | .025 | -.040 |
| 7 | .150 | .358 | .125 | .039 |
| 8 | .122 | .304 | .206 | .113 |
| 9 | .126 | .357 | .176 | .112 |

*Reference junction was in a steam bath open to the air.

Run 126

Single-Phase Laminar

| | |
|---|---|
| Water feed rate: | 96.5 lbs/hr |
| Current intensity: | 278 amps |
| Current potential: | 10.8 volts |
| Inlet pressure: | —— |
| Inlet temperature: | 109.5 $^{o}$F |
| Exit quality: | 0.1 per cent vapor |
| Average heat flux: | 8,300 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | -.730 | -1.255 | -1.777 | -1.785 |
| 2 | -.375 | -1.053 | -1.605 | -1.567 |
| 3 | -.492 | -.670 | -1.324 | -1.232 |
| 4 | -.455 | -.432 | -1.070 | -.908 |
| 5 | -.311 | -.231 | -.750 | -.55 |
| 6 | .073 | .070 | -.282 | -.285 |
| 7 | .17 | .21 | .010 | .043 |
| 8 | .10 | .22 | .22 | .12 |
| 9 | .11 | .11 | .24 | .06 |

*Reference junction was in a steam bath open to the air.

Run 127

Saturated Boiling

Water feed rate: 120.8 lbs/hr

Current intensity: 429 amps

Current potential: 16.65 volts

Inlet pressure: 1.38 psig

Inlet temperature: 215.2 °F

Exit quality: 20.9 per cent vapor

Average heat flux: 19,900 Btu/(hr)(sq ft)

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | .53 | .72 | .727 | .665 |
| 2 | .625 | .76 | .727 | .60 |
| 3 | .55 | .645 | .753 | .54 |
| 4 | .47 | .64 | .705 | .515 |
| 5 | .53 | .66 | .665 | .50 |
| 6 | .46 | .64 | .564 | .47 |
| 7 | .46 | .575 | .506 | .405 |
| 8 | .38 | .575 | .455 | .355 |
| 9 | .345 | .505 | .411 | .285 |

* Reference junction was in a steam bath open to the air.

Run 128

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 193.0 lbs/hr |
| Current intensity: | 425 amps |
| Current potential: | 16.5 volts |
| Inlet pressure: | 2.00 psig |
| Inlet temperature: | 217.3 °F |
| Exit quality: | 13.1 per cent vapor |
| Average heat flux: | 19,600 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longitudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | .613 | .780 | .767 | .700 |
| 2 | .650 | .835 | .764 | .680 |
| 3 | .602 | .742 | .764 | .630 |
| 4 | .558 | .755 | .701 | .584 |
| 5 | .640 | .736 | .667 | .562 |
| 6 | .526 | .656 | .564 | .508 |
| 7 | .518 | .572 | .503 | .434 |
| 8 | .432 | .552 | .450 | .382 |
| 9 | .383 | .478 | .396 | .304 |

* Reference junction was in a steam bath open to the air.

Run 129

Saturated Boiling

| | |
|---|---|
| Water feed rate: | 190.0 lbs/hr |
| Current intensity: | 544 amps |
| Current potential: | 21.3 volts |
| Inlet pressure: | 4.05 psig |
| Inlet temperature: | 222.0 $^{o}F$ |
| Exit quality: | 22.3 per cent vapor |
| Average heat flux: | 32,500 Btu/(hr)(sq ft) |

Temperature readings*, millivolts:

| Longi-tudinal station | Circumferential location 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1.127 | 1.198 | 1.144 | 1.132 |
| 2 | 1.210 | 1.333 | 1.157 | 1.106 |
| 3 | 1.135 | 1.250 | 1.132 | 1.032 |
| 4 | 1.008 | 1.225 | 1.025 | .925 |
| 5 | 1.003 | 1.117 | .953 | .858 |
| 6 | .837 | 1.008 | .848 | .773 |
| 7 | .808 | .894 | .777 | .681 |
| 8 | .687 | .836 | .696 | .586 |
| 9 | .592 | .715 | .601 | .469 |

* Reference junction was in a steam bath open to the air.

## APPENDIX G

### PRESSURE DATA FOR SMALL COIL

| Run | Water feed rate, lbs/hr | Current intensity, amps | Current potential, volts | Inlet pressure, psig | Inlet temp., °F |
|---|---|---|---|---|---|
| 3-P | 77.2 | 429 | 16.4 | 1.10 | 212 |
| 4-P | 77.3 | 542 | 20.95 | 2.09 | 212 |
| 5-P | 196.3 | 865 | 33.0 | 12.70 | 222 |
| 6-P | 195.0 | 688 | 26.25 | 7.13 | 211 |
| 7-P | 121.1 | 544 | 20.95 | 3.04 | 218 |
| 8-P | 124.0 | 684 | 26.05 | 5.48 | 216 |
| 14-P | 78.5 | 682 | 26.0 | 5.05 | 217 |
| 16-P | 124.5 | 865 | 33.0 | 10.72 | 224 |
| 27-P | 118.8 | 428 | 16.4 | 1.44 | 215 |
| 28-P | 189.7 | 425 | 16.25 | 1.98 | 216 |
| 29-P | 193.5 | 545 | 20.95 | 4.20 | 223 |

PRESSURE DATA FOR SMALL COIL (Continued)

| Run | $P_1$ psig | $P_3$ psig | $P_5$ psig | $P_7$ psig | $P_9$ psig | $P_{94}$ psig |
|---|---|---|---|---|---|---|
| 3-P | 1.04 | 0.94 | 0.90 | 0.68 | 0.33 | 0.33 |
| 4-P | 2.08 | 2.12 | 1.80 | 1.36 | 0.57 | 0.62 |
| 5-P | 12.41 | 11.21 | 10.63 | 8.59 | 4.21 | 4.61 |
| 6-P | 6.98 | 6.80 | 6.17 | 4.88 | 2.39 | 2.53 |
| 7-P | 2.89 | 2.90 | 2.51 | 1.93 | 0.88 | 0.93 |
| 8-P | 5.32 | 5.22 | 4.64 | 3.54 | 1.54 | 1.68 |
| 14-P | 4.94 | 4.74 | 4.35 | 3.63 | 2.39 | 2.53 |
| 16-P | 10.49 | 10.34 | 9.12 | 7.10 | 3.95 | 3.33 |
| 27-P | 1.30 | 1.24 | 1.14 | 0.89 | 0.45 | 0.45 |
| 28-P | 1.82 | 1.79 | 1.54 | 1.20 | 0.57 | 0.61 |
| 29-P | 4.05 | 3.92 | 3.45 | 2.69 | 1.35 | 1.40 |

Note: Subscripts on P refer to station numbers.

# APPENDIX H

## ERROR ANALYSIS

First, the accuracy of the various measurements and the reliability of the calculated numbers will be presented; in the light of that, an appraisal of the final correlation can be made.

Although the runs have been classified into two groups—stable and unstable—this is in fact a relative term. Even in the stable runs a fluctuation of 10-20 per cent in the total pressure drop of the system over a period of one to two seconds was not uncommon as could be seen on the oscillograph. In the measurement of pressure, the rapid fluctuations were damped by adjusting a valve in the pressure line to the manometer.

The pressure fluctuations caused a fluctuation in flow and the saturation temperature with a subsequent oscillation in the thermocouple readings. The rapid fluctuations were damped in the tube wall, but the slow ones caused drifts of about 1 $^{o}$F in the thermocouple reading. Under such conditions an attempt was made to record an average value for the thermocouple reading.

The error in thermocouple calibration and the extrapolation of the calibration to temperatures above 212 $^{o}$F is estimated to be less than $\frac{1}{2}$ $^{o}F$ and usually much less. For the few cases where the temperature was above 300 $^{o}F$ the error may be as large as 1 $^{o}F$.

The error in calculating the temperature drop through the wall arises from two sources: the accuracy with which the wall thickness is measured and the accuracy with which the temperature profile on the outside of the tube wall is known, since the radial and circumferential conduction heat fluxes depend on the latter consideration.

The wall thickness was determined by weighing the coil and using the value of the specific weight of the metal (see Appendix D). Since the weighing was accurate to one part per 2000, the accuracy of the wall thickness was as good as that of the specific weight, which may be one per cent. A one per cent error in the wall thickness introduces an error of approximately two per cent in the value of the temperature drop through the wall. This error is consistently the same in all the calculations; so, it would not cause a scatter in the data.

The effect of the uncertainty of the outside temperature profile on the calculated temperature drop through the wall is quite small——less than one per cent——when the temperature difference between the concave and the convex side of the tube is under 50 $^{o}F$ and when the profile conforms to Fig. B-1. When the outside temperature profile is of the type of Fig. B-2, the possible error in the calculation of the temperature drop and flux is greater;

and, the larger the difference between the temperature of the adjacent points, the greater the possible error—perhaps as much as 25 per cent.

In the range of steam qualities above 90 per cent, the uncertainty in the calculated heat transfer coefficient may become high. To alleviate the problem, one must install as many as 12 small gauge thermocouples on the periphery of the tube in order to obtain a better temperature profile; the net circumferential conduction at any point depends on $\frac{\partial^2 T}{\partial \phi^2}$.

The steam quality is calculated from the water feed rate and the heat input to the coil. Therefore, an error of one per cent in the power input or in the feed rate introduces an error of 18 per cent in the calculated value of $X_{tt}$ when the quality is 95 per cent and correspondingly higher errors at higher qualities. Still another complicating factor in the very high quality range was the wide fluctuation of temperature at the top and bottom positions of the tube.

The accuracy of the voltmeter and the ammeter were guaranteed to be within one per cent of their full range. In Runs 20 and 120, where the feed stream was completely vaporized, a heat balance was made on the system. The agreement between the heat supplied by the generator and the heat transferred to the fluid was within one per cent; the heat loss was considered in the heat balance.

Changes in the atmospheric pressure introduce a possible error of about 0.5 psi in the pressure measurements and 2 $^{\circ}F$ in the saturation temperature. This error in the pressure measurement affects the value of the Lockhart-Martinelli parameter by approximately 1.5 per cent. The corresponding error in the value of the temperature affects only the physical properties. The effect of the latter error on the heat transfer coefficient is estimated to be about one per cent.

It is estimated that in the quality range below 80 per cent, the accuracy of the calculated average heat transfer coefficients is within 10 per cent. It gradually becomes worse at higher qualities until at 95 per cent quality it is estimated to be within 25 per cent.

## APPENDIX I

## CALIBRATION OF THERMOCOUPLES AND ROTAMETER

### TABLE I-1

### CALIBRATION OF THERMOCOUPLES FOR SMALL COIL

| Longitudinal stations | Circumferential locations 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | -.022 | -.010 | -.020 | -.018 |
| 2 | -.020 | -.020 | -.045 | -.025 |
| 3 | -.010 | -.006 | -.018 | -.018 |
| 4 | -.018 | -.013 | -.024 | -.041 |
| 5 | -.027 | -.010 | -.019 | -.048 |
| 6 | -.021 | -.030 | -.020 | -.035 |
| 7 | -.014 | -.002 | -.010 | -.025 |
| 8 | -.031 | -.022 | -.030 | -.040 |
| 9 | -.010 | -.010 | -.010 | -.057 |

Note: The numbers in this table are the thermocouple readings in millivolts when steam was bled through the coil and the reference junction was a steam bath at atmospheric pressure. It is noticed that all the thermocouples indicated low readings.

TABLE I-2

CALIBRATION OF THERMOCOUPLES FOR LARGE COIL

| Longitudinal stations | Circumferential locations 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | −.073 | −.032 | −.049 | −.020 |
| 2 | −.024 | −.018 | −.042 | −.028 |
| 3 | −.063 | −.056 | −.058 | −.050 |
| 4 | −.072 | −.032 | −.072 | −.051 |
| 5 | −.030 | −.025 | −.028 | −.042 |
| 6 | −.082 | −.051 | −.041 | −.040 |
| 7 | −.045 | −.071 | −.054 | −.057 |
| 8 | −.063 | −.045 | −.052 | −.047 |
| 9 | −.065 | −.067 | −.074 | −.080 |

Note: The numbers in this table are the thermocouple readings in millivolts when steam was bled through the coil and the reference junction was a steam bath at atmospheric pressure. It is noticed that all the thermocouples indicated low readings.

TABLE I-3

CALIBRATION OF ROTAMETER

| Rotameter reading | Water flow rate, lbs/hr |
|---|---|
| 24.05 | 200.3 |
| 22.00 | 177.5 |
| 19.95 | 155.4 |
| 17.85 | 134.5 |
| 16.03 | 116.7 |
| 14.03 | 97.5 |
| 12.00 | 80.4 |
| 10.00 | 62.9 |
| 8.95 | 55.3 |
| 8.05 | 48.6 |
| 7.15 | 41.7 |
| 6.05 | 33.7 |
| 4.90 | 25.6 |

Note: Water temperature was 100–110 $^{\circ}$F at the inlet of the rotameter.

## APPENDIX J

## CHARACTERISTICS OF GALVANOMETERS*

The galvanometers were manufactured by Consolidated Electrodynamics Corporation.

| | Galvanometer for measuring temperatures | Galvanometer for measuring inlet pressure |
|---|---|---|
| Type | 7-351 | 7-339 |
| External damping resistance required, ohms | 350 | 350 |
| Undamped natural frequency, cps | 20 | 50 |
| Terminal resistance (± 10%), ohms | 33 | 30 |
| System voltage sensitivity at 11.5 inch optical arm, in/mv | 0.982 | 0.572 |
| Maximum safe current, milliamps | 15 | 15 |

* Reproduced from "Galvanometer Users' Handbook", Consolidated Electrodynamics Corporation, 360 Sierra Madre Villa, Pasadena, California.

## NOMENCLATURE

| | |
|---|---|
| $A$ | heat transfer area $ft^2$ |
| $A_f$ | cross-sectional area for flow, $ft^2$ |
| $a$ | radial acceleration, ft $sec^{-2}$ |
| $a$ | $\frac{1}{2}(T_{hot} + T_{cold})$ see Fig. B1-b |
| $b$ | $\frac{1}{2}(T_{hot} - T_{cold})$ see Fig. B1-b |
| $c$ | correction to be added to thermocouple reading, millivolts |
| $C_{pl}$ | heat capacity of liquid, Btu $lb^{-1}$ $^oF^{-1}$ |
| $D$ | coil diameter, center to center, ft |
| $d$ | tube I.D., ft |
| EMF | thermocouple reading, millivolts |
| $f$ | Fanning friction factor, dimensionless |
| $G$ | heat generated in tube wall, Btu $ft^{-3}$ $hr^{-1}$ |
| $G$ | mass flux, $lb_m$ $hr^{-1}$ $ft^{-2}$ |
| $g$ | gravitational acceleration, 32.2 ft $sec^{-2}$ |
| $g_c$ | conversion factor, 32.2 $lb_m$ $lb_f^{-1}$ ft $sec^{-2}$ |
| $h$ | local heat transfer coefficient, Btu $hr^{-1}$ $ft^{-2}$ $^oF^{-1}$ |
| $\bar{h}$ | circumferential average heat transfer coefficient, Btu $hr^{-1}$ $ft^{-2}$ $^oF^{-1}$ |
| $h_{conv}$ | convective component of heat transfer coefficient, Btu $hr^{-1}$ $ft^{-2}$ $^oF^{-1}$ |
| $h_{fg}$ | latent heat of vaporization, Btu $lb_m^{-1}$ |
| $h_l$ | heat transfer coefficient for liquid flowing in a straight tube, Btu $hr^{-1}$ $ft^{-2}$ $^oF^{-1}$ |

| | |
|---|---|
| $h_{lc}$ | heat transfer coefficient for liquid flowing in a coil, Btu $hr^{-1}$ $ft^{-2}$ $^{o}F^{-1}$ |
| I | electric current intensity, amps |
| k | thermal conductivity of tube, Btu $hr^{-1}$ $ft^{-1}$ $^{o}F^{-1}$ |
| $k_l$ | thermal conductivity of liquid, Btu $hr^{-1}$ $ft^{-1}$ $^{o}F^{-1}$ |
| L | length, ft |
| l | heated axial length of tube from inlet, ft |
| P | pressure, $lb_f$ $in^{-2}$ absolute |
| Pr | Prandtl number for saturated liquid |
| q | heat transferred to boiling liquid, Btu $hr^{-1}$ |
| q' | total heat generated in coil, Btu $hr^{-1}$ |
| $q_{loss}$ | heat loss, Btu $hr^{-1}$ |
| R | coil radius measured to tube axis, ft |
| R | a function of r |
| $\mathcal{R}$ | resistance, ohm |
| $R_l$ | volume fraction of tube occupied by liquid |
| r | radial distance from center of tube, ft |
| $r_i$ | inside radius of tube, ft |
| $r_m$ | mean radius of tube, ft |
| $r_o$ | outside radius of tube, ft |
| Re | Reynolds number based on inside diameter of tube |
| T | temperature, $^{o}F$ |
| $T_i$ | inside wall temperature, $^{o}F$ |
| $T_{in}$ | liquid temperature at coil inlet |
| $T_o$ | outside wall temperature, $^{o}F$ |
| $T_{sat}$ | saturation temperature, $^{o}F$ |
| V | velocity, ft $sec^{-1}$ |

| | |
|---|---|
| $V$ | electric potential across coil, volt |
| $W$ | liquid flow rate at coil inlet, $lb_m\ hr^{-1}$ |
| $x$ | weight fraction of liquid vaporized |
| $x$ | distance measured along mid-point of tube wall, ft |
| $x'$ | distance measured along inside of tube wall, ft |
| $x_{out}$ | weight fraction of liquid vaporized at coil outlet |
| $X_{tt}$ | Lockhart-Martinelli parameter $\left(\frac{1-x}{x}\right)^{0.9}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\left(\frac{\mu_l}{\mu_v}\right)^{0.1}$ |
| $\Delta P_a$ | acceleration pressure drop, $lb_f\ ft^{-2}$ |
| $\Delta T$ | $T_i - T_{sat}$, $^oF$ |
| $\delta$ | local value of tube wall thickness, ft |
| $\delta_m$ | average value of tube wall thickness, ft |
| $\mu$ | viscosity $lb_m\ ft^{-1}\ hr^{-1}$ |
| $\pi$ | $\pi = 3.1416$ |
| $\rho$ | density, $lb_m\ ft^{-3}$ |
| $\sigma$ | liquid surface tension, $lb_f\ ft^{-1}$ |
| $\phi$ | angle measured clockwise from vertical, radian |
| $\Phi$ | a function of $\phi$ |
| $\phi_{gtt}$ | $[(dP/dL)_{TPF}/(dP/dL)_l]^{\frac{1}{2}}$ |

SUBSCRIPTS

| | |
|---|---|
| a | acceleration |
| c | coil |
| cr | critical |
| f | force |
| i | inside of tube |
| in | inlet of coil |

| | |
|---|---|
| l | liquid |
| m | mean |
| m | mass |
| o | outside of tube |
| out | outlet of coil |
| s | straight tube |
| sat | saturation |
| TPF | two-phase flow |
| v | vapor |