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NOTICE TO AUTHORS

Manuscripts are to be submitted to associate editors of the appropriate section and *may* be submitted directly to the editor in chief. Clear manuscript, preferably typed, with wide margin to the left, with double spacing between lines, is desirable. Please try to follow the typographical style of the most recent issue of the BULLETIN. Line drawings should be submitted on Bristol board, or similar material, and done in India ink. Figure number should be written on this in pencil. Titles for drawings, with figure numbers, should be typed on a separate sheet. Please try to minimize footnotes. Appended references and bibliographies, clearly so marked, should be done in the style of the A.A.A.S. publication, *Science*.

Astronomy

GALILEO'S VISITS TO ROME

WALTER J. MILLER, S.J.
Vatican Observatory

Galileo's first visit to Rome took place in the year 1587. At the age of 23, he already aspired to a vacant professorship of mathematics in Bologna, and for this purpose he needed the support of influential people and the recommendation of eminent mathematicians One of those whom Galileo then visited in Rome, and who became his lifelong friend and correspondent thereafter, was the Jesuit Father Christopher Clavius, professor of mathematics at the Roman College almost uninterruptedly for 47 years. Clavius was known as the Euclid of the 16th century, and co-operated with Pope Gregory XIII in establishing the Gregorian calendar. Shortly after this 1587 visit, Galileo wrote from Florence to Father Clavius to ask his advice about the proof of a theorem concerning the center of gravity of solids. This autograph letter, the earliest extant letter of Galileo, is now in the archives of the Pontifical Gregorian University, successor to the Roman College when the latter was appropriated in 1873 by the Italian government during the unification of Italy.

Galileo's second (and happiest) visit to Rome was from March 29 to June 4, 1611. He was triumphantly received as the man of the hour. It is easy to see why. Galileo's discoveries in the field of mechanics could be understood only by the learned few, but his astounding telescopic discoveries could be understood by all alike, even though their real significance would not be fully grasped or commonly accepted for generations to come.

Galileo had first pointed his telescope at the skies in the late months of 1609, and sensational discoveries had been made and announced in rapid succession during 1610: mountains and craters on the moon, star clouds in the Milky Way resolved into immense numbers of stars quite different from the planets, four moons of Jupiter, the phases of Venus, the peculiar and puzzling egg shape of Saturn, and finally sunspots. All except the last were explicitly confirmed in detail from their own observations by the Jesuit astronomers

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Reprinted from SKY AND TELESCOPE magazine, published at Harvard College Observatory. This article was published in two parts in the issues of July and August, 1952. Father Miller writes that this article was written at the invitation of Mr. Charles A. Federer, Editor of the magazine, for the purpose of presenting a viewpoint different from the one presented in a previous article, *Galileo in Padua* by Rufus Suter. *Ed.*

of the Roman College, at a solemn academy held in Galileo's presence and in his honor in May of 1611. This must have been the high point of his visit to Rome, for at least three cardinals were present, along with many high ecclesiastics, theologians, scientists, and other eminent personages of Rome. To lend credence to the unprecedented discoveries, the telescope used by Father Clavius and his Jesuit collaborators to make the confirmatory observations was on public display.

On this occasion, the Latin word *perspicillum* was still used for the word telescope, although the new word *telescopium* had already been coined by Giovanni Demisiani and used in Rome by Federico Cesi, Marchese di Monticelli, at his banquet in Galileo's honor on April 14, 1611. Galileo was greatly pleased when Cesi enrolled him as the sixth member of his eight-year-old Accademia dei Lincei, on April 25th; and the Lincean album containing his signature on that occasion is still preserved at the modern home of this celebrated academy in Palazzo Corsini, No. 10 Via della Lungara. Thereafter, Galileo faithfully complied with the academy's rule that members must use the title of Linceo in their scientific publications, and he more than complied with the academy's ideal of studying the facts of nature with the close scrutiny of a lynx. Palazzo Cesi, where Galileo was entertained and honored, is located at No. 21 Via della Maschera d'Oro. An inscription on the facade commemorates the event, but the palace itself is now the seat of the Tribunale Supremo Militare of Rome.

Another feature of Galileo's 1611 stay in Rome was the triumphant demonstration of his telescope and its wonders, in the Giardino di Monte Cavallo (on the Quirinal Hill) at the residence of the Florentine Cardinal Ottavio Bandini. Among the many dignitaries present were Cardinals Bandini and Lorenzo Bianchetti, to whom Galileo also showed spots on the sun. At a dinner given in his honor by the Duca di Acquasparta (father of Federico Cesi), at his villa above San Pancrazio on the Janiculum Hill, Galileo once astounded the distinguished guests by showing them first the moons of Jupiter and then letting them read the inscription of Sixtus V above the Loggia delle Benedizioni at the Lateran Palace, over three miles away. Galileo displayed the moon and Venus through his telescope, to the Jesuit Cardinal Robert Bellarmine and to many others. Galileo's letter of April 22, 1611, to his Florentine friend, Filippo Salviati, reports that various prelates and princes had been just as much impressed by looking at celestial objects through his telescope as he himself had been in viewing all their marvelous statues, paintings, room decorations, palaces, and gardens—so we know that Galileo did his full share of tourist sightseeing in Rome.

The same letter also tells about the very cordial audience he had had that very morning with Pope Paul V (Camillo Borghese). Galileo was introduced to the Pope by the Tuscan ambassador to the Holy See, Giovanni Niccolini, at whose residence (in Palazzo Firenze, still existing today at No. 27 Piazza Firenze) Galileo was then staying in virtue of his new (June 10, 1610) official position as court philosopher and mathematician of Cosimo de'Medici II, grand duke of Tuscany. Writing to the latter on May 31st, Cardinal Francesco Maria dal Monte says that Galileo's visit had given such great satisfaction to all that, if they were living in the times of the ancient Roman republic, they would surely have erected a statue on the Capitoline Hill to honor him for his genius and his remarkable discoveries.

Galileo had long since been convinced of the truth of the Copernican doctrine that the earth rotates daily on its axis and revolves annually about the sun. In 1596 his astronomer friend, the celebrated Johannes Kepler, had had a work, *Prodromus Dissertationum Cosmographicarum*, condemned as heretical by the Protestant theological faculty of Tübingen, for its advocacy of the "anti-scriptural" Copernican theory. On August 4th of the following year, Galileo wrote to Kepler, saying that he himself had embraced the opinion of Copernicus many years ago, after having used the theory to explain many natural effects that were inexplicable by the commonly prevailing Ptolemaic hypothesis. He had never dared to publish either his researches or his refutation of adversaries, being "afraid of the lot of Copernicus, our teacher, who, although he did acquire immortal fame with some few, yet with an infinite number of people (for such is the number of the stupid) he came forth only to be laughed at and hissed off the stage."

If Galileo had already convinced himself of the truth of the Copernican theory many years before 1597, surely we may imagine how the discoveries he made in 1610 and the enthusiastic reception he received in Rome in 1611 encouraged him thereafter to become the fearless and even reckless public champion of Copernicanism. Today it is clear that never in his lifetime did Galileo possess a really valid proof of this theory, and the proof from the ebb and flow of the tides on which he laid so much stress was even completely false. But his penetrating intuition immediately realized the full significance of the phenomena his telescope enabled him to observe, and he impetuously set out to show everybody, willy-nilly, that the Ptolemaic interpretation of the facts was false.

It is important to try to understand why Galileo's opponents were so obstinately conservative. It was not only that the Ptolemaic theory had been taught as incontrovertible fact for centuries past by both scientists and philosophers. It was not only that ordinary everyday people were convinced from the evidence seen by their own eyes that the sun did move daily from east to west and yearly through the signs of the zodiac. But also and much more, it was due to the fact that in those days both Protestants and Catholics alike considered the Bible to be the supreme authority not only in theology but also in science.

For instance, take the famous initial text in *Ecclesiastes* (the

Preacher) where Solomon, after summing up life with the words, "Vanity of vanities, and all is vanity," goes on to say: "One generation passeth away, and another generation cometh; but the earth standeth forever. The sun riseth, and goeth down, and returneth to his place; and there rising again, maketh his round by the south, and turneth again to the north." That text, taken literally, could mean only that the sun and not the earth did the moving.

In the absence of valid proof to the contrary, lay people and theologians alike in those days suspected as heretical any new and revolutionary doctrine which would interpret such texts in a way that contradicted the obvious and literal sense of the words. There was no question of being inimical or unfriendly to science; to the mind steeped in the traditional interpretation of Scripture and not yet converted from the authority of Aristotle to the modern method of scientific observation, it seemed that the Copernican doctrine was radically false and unscientific, precisely because it appeared anti-scriptural and therefore heretical.

Galileo correctly answered (in the very words suggested to him by Cardinal Cesare Baronio) that Holy Writ is intended to teach men how to go to Heaven and not how the heavens go. In other words, the Bible is not a book of astronomy, nor does it aim to teach science, and in speaking of celestial phenomena it uses current expressions which would be intelligible to ordinary people thinking and speaking according to the obvious appearances of things; and these expressions are not intended to explain the phenomena or to state anything about the true structure of the heavens.

Galileo's third visit to Rome was from December 11, 1615, until June 1, 1616. The reason for the visit was Galileo's desire to defend on the spot his views on the relation between faith and science. On December 21, 1613, he had written a letter to his former pupil of Padua, the Benedictine Father Benedetto Castelli, and in 1615 he wrote an even longer letter (running to 40 printed pages in the 20-volume *Edizione Nazionale* of Galileo's works) to the dowager grand duchess of Tuscany, Cristina di Lorena; in both letters he brilliantly explained how the disputed passages of Scripture were to be reconciled with Copernicanism.

These and other such letters of Galileo were often recopied and widely circulated, and the Dominican Fathers of Florence had asked Cardinal Paolo Sfondrati, the prefect of the Roman Congregation of the Index, to investigate the orthodoxy of the letters. However, since the letters had not been printed, the question was turned over to Cardinal Giovanni Millini, the secretary of the Holy Office or Inquisition, whose function it was to guard the faithful from danger of false doctrines. The mild and informal decision was that a few passages which at first sight seemed objectionable could be taken in a good sense, and that on the whole there was no divergence from Catholic doctrine. Unfortunately, Galileo was not content with this negative vindication. His friends advised and implored him to avoid theology and to confine himself to mathematics and physics ("Write freely but be careful to keep outside the sacristy!"). They begged him to be satisfied with teaching Copernicanism as a hypothesis, but he insisted on teaching it as a proved fact. Orally and in writing he campaigned actively, in private and in public, before eminent personages in ecclesiastical and lay circles in Rome, for a winner-take-all decision.

The discussion thus seemed no longer personal but rather doctrinal in nature, and Galileo's many enemies could urge to the Holy Office the necessity of removing once and for all the uncertainty concerning the relations between Copernicanism and Christian tradition. Galileo's 1613 book on sunspots (which was published in Rome by the Accademia dei Lincei with papal imprimatur from the master of the Sacred Palace) contained passages openly teaching Copernicanism as a fact, and so it was denounced to the Holy Office. Thus was the stage set for the tragedy of Galileo.

On February 19, 1616, 11 qualifiers of the Holy Office were asked for their opinion on two propositions extracted from the book. These clergymen were experts in sacred theology and not in natural science, and it is typical of the times that their opinion was asked and given not so much on the scientific evidence for the theory as on its theological implications. On February 24th these consultors submitted to the cardinals, members of the tribunal of the Inquisition, the following unanimous opinion.

1. The proposition that the sun is the center of the world and is entirely immovable from its place is stupid and absurd philosophically, and formally heretical, because it expressly contradicts statements made in many places of Sacred Scripture, according to the literal meaning of the words and according to the common explanation and opinion of the Holy Fathers and learned theologians.

2. The proposition, that the earth is neither the center of the world nor immovable, but that it moves as a whole and also with a diurnal motion, is open to the same censure in philosophy and, theologically considered, is at least erroneous in faith.

The next day Pope Paul V presided over the usual Thursday plenary session of the cardinals of the Inquisition, in the Dominican Convent of Santa Maria sopra Minerva, in Piazza Minerva near the Pantheon. The verdict of the consultors was accepted, and the Pope asked Cardinal Bellarmine to send for his friend Galileo and advise him to relinquish his opinion. Failing that, the Dominican commissary of the Holy Office was to command Galileo in the presence of witnesses thenceforth not to teach, defend, or discuss this opinion verbally or in writing, under pain of imprisonment.

Since Galileo would not yield to Bellarmine's persuasion, the Dominican Father Michelangelo Segizzi, commissary of the Holy Office, at once imparted the solemn admonition to Galileo in the apartments of Cardinal Bellarmine on February 26, 1616; and Galileo promised to obey. Due to this submission, the subsequent decree of the Congregation of the Index, dated March 3, 1616, spared Galileo from any public prohibition of his books, although it did prohibit Copernicus' book *De Revolutionibus Orbium Coelestium* until a few verbal corrections were made to show that the Copernican doctrine was taught only as a hypothesis for explaining the observed facts of astronomy. On March 11th Galileo had a most cordial, three-quarter of an hour audience with Paul V, to whom he confessed his fear of being thereafter continually persecuted by his calumniators. The Pope answered that both he and the Congregation had the highest opinion of his integrity of life and sincerity of mind, and neither would easily believe any such calumnies against him. Paul V assured him repeatedly that, as long as he would be Pope, Galileo would be safe and even favored on every possible occasion.

Quite definitely the Congregations of the Holy Office and the Index were in error. Even though the consultors could rightly disagree with those who believed that Galileo's observations had already proved that heliocentric hypothesis to be a fact, still these same consultors had been amply warned of the possibility that the theory might later be proved a fact after all. They had closely examined Galileo's irreproachable reconciliation of the Scripture texts with his observations. They knew that he cited the authority of St. Augustine, St. Jerome, St. Thomas Aquinas, and others who taught that the Bible does not aim to instruct us on the nature of the phenomena but limits itself to describing the appearances of things and for this purpose uses the terms in current usage. Legitimately, the Congregations could have issued a strictly disciplinary decree forbidding Galileo to teach or even to hold the Copernican doctrine as a proved fact. But when the consultors and the Congregations and even the presiding Pope concurred in stigmatizing the doctrine as anti-scriptural and heretical, they made a lamentable mistake which with due care and caution they could have avoided on the basis of the evidence they already had in their possession. Though the implicit condemnation of Copernicanism as heretical in no way concerns papal infallibility (since Catholic doctrine attributes that prerogative only to the Pope's solemn *ex cathedra* decisions and not to the decrees of Congregations), still the blunder was a grave one. Human prejudices and human passions may partially explain but they cannot excuse this, the crucial error in the tragedy of Galileo as we see it today.

Galileo for a few days before the end of his 1611 visit had stayed with the grand duke's newly appointed ambassador, Piero Guicciardini, at Villa Medici, Trinita dei Monti (now the seat of the Académie Française). During the 1616 visit, and also during his next two sojourns in Rome, the Villa Medici was his usual abode. Its delightful gardens on the Pincian Hill were not only a constant joy for the country-loving scientist, but also enabled him in peace and quiet to prolong his telescopic observations of the skies until late hours of the night. In fact, some of his 1616 Roman observations of Jupiter's moons have come down to us, with the times reckoned in hours and minutes from noon and specified *juxta orologium Trinitatis.*

Galileo's fourth visit to Rome was from April 23 to June 11, 1624. The occasion of this trip was the accession of his friend of 12 years standing, the Florentine Cardinal Maffeo Barberini, to the papal throne as Urban VIII on August 8, 1623. Galileo's book, *Il Saggiatore,* on the nature of comets, appeared a few months later and bore a dedication to the new Pope. Urban VIII was much pleased, and even had the work read to him at table. Under such exceptionally favorable conditions, the ever-sanguine Galileo hoped to have the prohibition against his advocacy of Copernicanism removed once and for all.

During those seven weeks in Rome, Urban VIII granted Galileo no less than six private audiences, the first one being for more than an hour. In the fifth audience the Pope showed his esteem of Galileo by gifts of a painting, a silver and a gold medal, and some religious objects. In the last audience he promised Galileo a benefice for his son Vincenzio. However, there seemed no hope of his revoking the decree of 1616. According to Galileo's friend, Cardinal Eitel Friedrich von Hohenzollern, Urban VIII replied to the cardinal's intercession in favor of Copernicanism by saying that there was no fear that any one would ever be able to prove the Copernican theory as necessarily true.

Galileo's fifth visit to Rome lasted from May 3 to June 26, 1630, and was concerned with (though only partially successful) obtaining a papal imprimatur for his great *Dialogo sopra i due massimi sistemi del mondo.* There are allusions to this work (which at first was intended to have the title: On the Ebb and Flow of the Tides) in Galileo's letters ever since his return from Rome to Florence in 1624, but the book was not completed in its final form until the beginning of 1630. The *Dialogues* consisted of a lively discussion of the relative merits of the Ptolemaic and Copernican world systems, but Galileo's own letters and the text itself make it abundantly clear that the arguments which his spokesman proposed in the *Dialogues* were intended by Galileo to demolish the geocentric hypothesis once and for all.

The negotiations for the imprimatur dragged on until May of 1631, both because of the reluctance of the appointed censor, Niccolo Riccardi, O.P., master of the Sacred Palace, and because of an outbreak of cholera in Rome. The plague prevented Galileo's returning to Rome in 1631 or even the easy exchange of criticisms and corrections. Hence, in view of Galileo's impatience to get the *Dialogues* in print, the inquisitor of the Holy Office in Florence was delegated to censor the book, the following very revealing instructions being given to him on May 24, 1631, by Father Riccardi, his fellow Dominican.

"The mind of His Holiness is that the title and subject is not to be the ebb and flow of the tides, but unconditionally is to be the mathematical consideration of the Copernican theory of the earth's motion, with the intention of proving that, apart from divine revelation and sacred doctrine, this theory could save the appearances and answer all the objections which might be adduced either from experience or from Aristotelian philosophy; however, absolute truth is nowhere to be conceded to this theory but only hypothetic truth, that is, apart from the Scriptures. Also it must be shown that this work is written only to show that all the reasons are known which can be brought forward to support this theory, and that the theory banned in Rome has not been banned for lack of knowing those reasons."

The printing of the *Dialogues* was finally finished on February 21, 1632, and at once a great furore ensued. This was partly due to personal complications. In 1624, Urban VIII himself had given Galileo a metaphysical argument which the Pope believed was an unanswerable proof of the falsity of the Copernican theory. At that time the Pope insisted on having this argument included in Galileo's contemplated book on the heliocentric and geocentric hypotheses. The two intelligent persons in the *Dialogues* are Salviati, a thinly veiled model of Galileo arguing skillfully for Copernicus, and Sagredo, the equivalent of Mr. Common Sense. The third person is Simplicio, the foolish simpleton who represents the Aristotelian philosophers, and whose naive and faulty reasoning in favor of the Ptolemaic views is so facetiously refuted that he soon becomes a laughingstock for the intelligent reader. Unfortunately, Galileo put the Pope's own argument in the mouth of Simplicio, without other comment than to have Salviati say, "A wonderful and truly angelic doctrine!" Galileo was certainly not foolish enough to wish to make fun of the Pope in a book whose very publication depended on having the papal imprimatur. But the imprudence furnished Galileo's many enemies with an opportunity that they gleefully utilized to the full, by trying to poison the mind of Urban VIII against Galileo.

However, too much importance should not be ascribed to the incident of Simplicio. We have the Pope's own repeated assurances both that he believed Galileo never intended ridiculing him, and that the Pope's chief concern was the "very serious danger for all of Christendom." Urban VIII held that it was no longer a question of a mathematical theory but rather of impugning the veracity of Sacred Scripture. The Pope was much displeased when he found out that Galileo had patently flouted the 1616 decree forbidding him to teach Copernicanism, which had been declared by competent ecclesiastical authority to be contrary to the Sacred Scriptures. Contempt for the Church's authority in that day and age was not to be tolerated even in his friend.

The Pope at once set up a special commission to make a full investigation both of the book and its doctrines and of the manner in which the imprimatur had been obtained without his knowledge. On April 17, 1633, after a month's work, the commission handed in its report, complete with detailed proofs of a fact nobody could deny, that Galileo had taught Copernicanism as a fact in flagrant disobedience of the 1616 prohibition. In spite of the intercession of Galileo's patron, the grand duke of Tuscany, and of other influential personages, Urban VIII inflexibly insisted that the question be turned over to the Roman Inquisition for the routine process of that ecclesiastical court. Meanwhile, Galileo had been summoned peremptorily to Rome, where he arrived finally on February 13, 1633, on his sixth (and saddest) visit, which ended with Galileo in disgrace and a nominal prisoner of the Holy Office for the remaining nine years of his life.

The proceedings of the Inquisition in 1633 were not concerned with the truth or falsity of the heliocentric hypothesis, but only with the disciplinary question of Galileo's disobedience. Galileo was personally examined by the commissary of the Inquisition on April 12, April 30, and May 10, 1633. On June 16th Urban VIII presided over the decisive plenary meeting of the Holy Office, in the Quirinal Palace (now the official home of the president of Italy, as it was the home of Italy's kings since 1873). The pope gave orders that Galileo was to recant before a full session of the Holy Office, was to be condemned to prison at the discretion of the same Congregation, and was to be forbidden thenceforth to discuss in writing or in speaking either the Ptolemaic or the Copernican hypothesis.

Accordingly, on June 21st Galileo was summoned once more before the Inquisition, and in response to a question three times repeated, he abjectly affirmed under oath: "I do not hold and have not held this opinion of Copernicus since the command was given me that I must abandon it." On June 22nd the solemn ceremony of the condemnation of Galileo and his public abjuration took place in the Aula Grande or Great Hall of the Inquisition. The sentence was first read to him, and then Galileo on his knees read the prescribed abjuration and signed the document. The apocryphal story (first appearing in print only in 1761) that Galileo in rising from his knees muttered to himself the words, "Eppur si muove" ("And yet it does move"), seems to be only an interesting fable. The documents of the 1633 process and those from 1616 as well are still preserved in the archives of the Vatican library, and have been published in full in Vol. XIX of the *Edizione Nazionale*.

During 15 of the 20 weeks of Galileo's last sojourn in Rome, he lodged with his close friend, Francesco Niccolini (now Tuscan ambassador, as his father Giovanni was before him), in Palazzo Firenze. After the abjuration, Galileo's last days in Rome were spent in custody at Villa Medici, from June 24 until July 6, 1633, the day of his final departure from Rome. About three weeks were spent (April 12-30 and June 21-24) in light confinement in rooms normally occupied by the Inquisition officials on the second floor of the Convent of Santa Maria sopra Minerva.

In 1873, more than half of the Dominican Convent was appropriated by the Italian Government (as was also the nearby Roman College of the Jesuits, which was likewise closely associated with Galileo), and the 1927 Lateran Pact settlement of the Roman question legalized these and other seizures. Since a Dominican house of studies still remains in the unappropriated part next to the church, and since the cloister garden (where Galileo was permitted to walk) gives the only open view of the rooms on the second floor where Galileo was a prisoner of the Inquisition, it is worthwhile asking the porter at No. 42 Piazza della Minerva (illustrated on page 213 last month) for permission to enter. One of the Dominican fathers will point out where the really severe underground prisons of the Inquisition used to be, and also the narrow stairs by which the cardinals were wont to go up from the cloister portico to the second-floor Great Hall where the plenary meetings of the Holy Office were held. The wing on that side of the cloister is the property of the Italian ministry of posts and telegraphs.

This same government ministry has maintained the Aula Grande, scene of Galileo's abjuration, in excellent condition. This hall on the second floor is now used as the minister's private library, and the lamps on the long central table even have lampshades bearing the words, "Eppur si muove." (Permission to visit this interesting scientific shrine may be readily obtained from the *Ufficio Informazioni* at the main entrance, No. 76 Via del Seminario.) A few minutes spent in this dimly lighted and solemn room bring the reverent pilgrim in spirit to the culminating moment of the tragedy of Galileo.

Biology

APPLICATION OF PHYSICS AND CHEMISTRY TO MODERN BIOLOGICAL RESEARCH

MICHAEL P. WALSH, S.J.

I. Changed Emphasis in Biological Research.

The average non-biologist perhaps because of limiting his biology to a one year course has the impression that biology is a subject full of terminology, purely descriptive, where you spend most of your time in the laboratory, cutting up a frog or a cat. Fifty years ago, biology was just that. In fact, all research in biology, especially with the birth of evolution, was concerned with the investigation of as many plants and animals as possible. If someone found something distinctive in a certain plant, ten other biologists went looking into other plants to see if they could find the same thing. Most of our books and articles, written fifty years ago, (or, even as recently as thirty years ago), were concerned almost exclusively with purely descriptive details. Today, there is a completely different slant in biology, beyond the basic elementary courses.

Today, for instance, a course in cytology, which is the science concerned with the study of the cell, is quite different. Fifty years ago, the cytologist was interested in finding out whether every plant and animal had a cell, what were the shapes and sizes of the cell. Today, however, the emphasis is almost completely on the chemistry of the cell.

In the field of genetics until about ten years ago the only animal that was studied at great length in genetics was the fruit fly. Biologists all over the world collected all the morphological facts they could for the fruit fly. They watched, for instance, to see whether inheritance governed the size of a wing, the size of an eye, the color of the eye. Within the last decade, we have seen the fruit fly replaced by a simple little mold, which many of you have seen on bread, the pink bread mold (Neurospora). In these studies, the emphasis now is placed on the inheritance of biochemical and physiological characteristics.

In the field of embryology it is the rare scientist today who is interested in knowing the various stages of an embryo. He is more concerned today with the answers to the questions: "How did those stages arise?" and "What is the chemistry behind them?" His work is more experimental.

Even in a course which many of you may be acquainted with, like histology, which basically is microscopic work, the whole emphasis is histo-chemistry or histo-physiology.

In the study of insects, our research men in the government, until the last decade, were concerned mostly with collecting insects, classifying them, studying their shapes and forms. Today, in every entomology department with which I am acquainted in the East, the emphasis is to a great extent on the physiology of the insects.

Our research institutions, like the famous Biological Institute, which is so close to us, the Woods Hole Marine Biological Laboratory, from its foundation in the latter part of the last century until 1942, was concerned with and devoted to an almost exclusive study of natural history. Today, about forty per cent or more of that Laboratory is devoted to research in radio-biology, physiology and biochemistry. At least fifty per cent of the Laboratory is staffed in the summer time by research men from medical and biochemical laboratories.

In research on plants, one of the most famous institutions in the East is the Bronx Botanical Gardens, located just across the street from Fordham. Until about ten years ago, almost every member of the staff was interested only in classifying plants collected from all parts of the world, and in preserving them in their herbaria. However, ten years ago, the directors of the Botanical Gardens were changed; plant physiologists replaced the taxonomists; and during the past five or six years we have seen two or three very important little microbes from the soil which were discovered there and now are known to be productive of antibiotics. Here again is a chemical or physiological problem.

If I may be pardoned for speaking of home, I think I might finish up my few words on the changed emphasis to chemistry by speaking of some research projects that have been done in the past few years at Boston College. The biology laboratories with their array of glassware and apparatus look like chemistry laboratories. We have done quite a few studies on decompression or simulating conditions at high and low altitudes to study the effects there on the chemistry of the blood, the content of cholesterol, lipids, carbohydrates, etc. Another group of experiments has to do with cold acclimatization. In our laboratory, we have raised hamsters in our refrigerators—all over the building, in fact—to observe what happens to the hamster when subjected to very high or low temperatures. What happens when you burn the paws of the hamster and affect the circulation of the blood. With the help of Father Devlin, of the Physics Department, we have done experiments in spectrophotometry. The identification of three hormones in Invertebrates that were not known before have been made by a couple of the students.

Studies in respiration have also been made. Mr. Alwyn Harry, S.J., did work on determining respiration rates in tissues, again, biology of a chemical nature. We have also worked a good deal in determining the effect of chemicals on cells. There is one chemical known to have some effect on cancer; it is called aminopterin, and its effect, especially on the nucleus, has been studied in great detail by several of the students. Doctors have found that, if cortisone is administered to a person with inactive tuberculosis, the disease was activated. We now have a professor and several students who are trying to find out why cortisone has that effect, and how cortisone works. We have confirmed, by studies on white mice, that cortisone definitely does increase the number of bacteria in white mice, no matter what type of bacteria.

In all the above, you have a rather brief summary of about 98% of the research work that we have carried out; and, as you can see clearly, it is almost entirely chemistry and physics. The influence of physics on modern biological research, however, has perhaps been even greater than that exerted by chemistry. The extent of this influence may be seen at once if we mention only a few of the many instruments which are so prominent in biological research laboratories today: the electron microscope, the colorimeter, the spectroscope, and the microscope. Certainly the most important tool borrowed from physics for application in present day biological research is radiation. Radiation has been used in three different ways by the biologist: first, as a tool to broaden our basic knowledge of vital processes; secondly, as a means of studying the damage done to living tissues by improper exposure to radiation; and, finally, as a method of therapy in the care of various disorders.

II. Current Radiation Studies

The bulk of the work in radiation has been done in three fields of biology: the field of genetics, which is concerned with inheritance; the field of physiology, which is concerned with the functions of animals and plants; and then, the field of pathology, or diseases. In the plant kingdom radiation has been used perhaps much more than in the study of animals. Radiation has been used, in the plant kingdom, especially to bring together genetically new strains of crops. Thus, it is possible that, through radiation studies, we may be able to grow strains that are found nowhere else in the world, that have a strong resistance to drought and a strong resistance to disease. But, in general, it has been found that radiation damages plants much more than it helps them, and that the proportion of the damage is related to the amount and rate of exposure to the radiation. If a plant is subjected to radiation, growth is retarded, the division of cells is blocked, and malformations occur all along the plant.

In the field of animal work, radiation has been used for really basic research. There is a great deal of speculation on just what happens in a living cell in the ultimate production of a fat or a carbohydrate, an amino acid or a fatty acid; and, with radiation, there is some hope that many of the steps along the way might be clarified and fully determined. Radiation is known to disrupt the complex molecular structure of many of the chemicals inside the animal.

These are just a couple of the research problems that are being worked out with radiation. But, most of the work that is being done by biologists in the field of radiation concerns the damage of radiation. Direct damage, for instance, was caused to the Curies when they got burns on their skin. Bleeding, loss of hair, and other ailments will occur to anyone that comes close to severe doses of radiation. It is known, for instance, that radiation will destroy the blood-forming tissues and, as a result, the cancerous condition, known as Leukemia, occurs. Furthermore, during the life-span of an individual who works with radiation, doses are known to accumulate in the body. If you take a dose of radiation today and take another one some years hence, the two doses accumulate and can be strong enough to cause anyone of these conditions, mentioned above. For instance, in atomic research laboratories, like the Brookhaven Institute and Oak Ridge, 0.1 Roentgen unit of radiation each working day is considered to be the tolerance dose; or, at least, was considered so about six months ago. And, now, 0.3 Roentgen unit is said to be the tolerance dose. It is thought for instance, by the physicists there, together with the biologists, and especially by those who know very little about the field of genetics, that one would not have any trouble if he allowed only 0.3 Roentgen unit to hit him each working day. But we know, from calculations that have been made, that if one is allowing this dosage for five years on every working day, his life-span will be shortened three years.

But, the more interesting feature is the indirect damage that radiation causes. You hear all sorts of stories, fantastic stories, on what the Atom Bomb at Hiroshima is going to do to the people a thousand years hence. Some have oftentimes said, and the Sunday supplements have printed it, that every one from that area is going to be a monster. And, then, you find physicists who fear to work in radiation laboratories because they fear that, if they do, all their children will be abnormal.

Now, these are the facts as we have gathered them from genetics, and I must emphasize they are only inferences that have been made from studies on fruit flies and mice. There is no work that has been done, except a little statistical work, on human beings, and the effect that radiation has on their genes. But, a good deal of work has been done on radiation effects on fruit flies; and, in the last five or six years, since the development of Atomic energy, experiments have also been carried on with mice. Of course, it has been known, since 1927 (the man who discovered this was H. J. Muller, now at Indiana University, who, twenty years later, received the Nobel Prize for his discovery) that radiation will always cause mutations, changes in the genes, or, as we used to call them, I think, in the philosophy text-books, "sports".

Now, in all the work that has been done on fruit flies, most mutations that arise either spontaneously from nature, or that we induce artificially, are harmful. Geneticists have never found a beneficial mutation. They have never been able to change a gene, therefore, and make progress in the development of the animal or plant. There are certain mutations, like changes in the color of the eyes, that we can call neutral, for the time being at least. No one knows whether a fruit fly with a red eye sees better than a fruit fly with a white eye. But, of all mutations that we have studied, over 90% of them are harmful to the organism. Moreover, there is no healing of this harmful damage. Once it is caused, it will stay there until another mutation comes, which, on studies made so far, would make the fly even worse than it was, as far as seeing or flying or whatever the characteristic might be. It is also known, from studies on the fruit fly, that there is no threshold dose—any dose of radiation, even the smallest, will induce a genetic change.

Theoretically, the total genetic damage of an atom bomb or a group of bombs on one generation would be great. Since, however, the mutations due to radiations would be lost in the large number of spontaneous mutations occuring in any single generation and deaths or diseases due to environmental conditions, it is believed by geneticists that the damage of the atom bomb in any single subsequent generation will not be noticeable. But, when we realize now that radioactive substances are fast coming into industry, and that they are being used widely in medicine, the geneticists warn those who will be handling products of atomic energy and radiation research that the amounts of radiation can accumulate through several generations. It is one thing to talk about one set of bombs as they affect one generation; but, when radiation in heavy doses is imposed on generation after generation, then—let us say in ten generations from the present one—noticeably harmful effects in the form of mutations will occur on a large scale. This then is the warning given by geneticists to those controlling atomic energy and to those in medical research.

From some of the things that I have already mentioned to you, you can see that radiation, without adequate protective techniques, can be exceedingly harmful. More striking perhaps is a consideration of the amounts of radiation expended in routine medical treatments. For example, an ordinary fluoroscope study, employed by physicians in studying a disorder in the stomach or intestines, induces some 75 Roentgen units. Doctors induce ovulation in women with 350 Roentgen units. They can stop the production of sperms in men, temporarily, and for the purposes of birth control, with dosages of 500 Roentgen units. The victims of the Hiroshima Bomb who survived had, as far as can be calculated, 150 Roentgen units. When you realize that this small amount per day, for a period of 400 days, doubles the rate of mutations, and that all mutations are harmful, then you can easily imagine what will happen if the indiscriminate use of radiation is continued for ten or fifteen generations. That is where the danger, as far as the genes are concerned, lies in radiation.

One very consoling feature is that a lot of the present day research on radiation is being done to prevent the effects of radiation. It is known, for example, that alcohol prevents mutations. So, when you see an atom bomb coming. . . . . . In general, we know that a lack of oxygen will cut down the rate of mutations and will prevent the effect of radiation on a living cell; alcohol is such a substance.

Lastly, in the field of radiation, we have radiation therapy. X-rays, beta-rays and other types of rays are being used to retard cancer. It is a strange thing that radiation can induce Leukemia, which is cancer of the blood, and it can also stop Leukemia. Radioactive phosphorus, when induced into the human organism in studying Leukemia, does everything that ordinary (non-radioactive) phosphorus can do. It has the same chemical properties; the only difference is that it has a different atomic weight; and, being radioactive, can be detected by sensitive recording instruments, even while it is actively engaged in the vital processes. By introducing radioactive chemicals, like phosphorus, into the human systems of both healthy and diseased persons, biologists and medical research men have hopes of putting radioactivity to work—not to destroy mankind, but to cure him.

Chemistry

THE RELATION OF MOLECULAR TO ELECTRONIC STRUCTURE IN CHEMISTRY

BERNARD A. FIEKERS, S.J.

In an earlier paper (1) it was pointed out that variable valence among the chemical elements can be accounted for, to a great extent, by the electronic structures of the atoms comprising the molecule, and especially by the orbitals of the central atom which are involved in bond formation. In this paper it is proposed to establish an introduction to the geometrical or stoichiometrical aspects of molecular structure by classifying molecular structures according to the bonding orbitals involved. It is hoped thus to establish a "bridgehead" between electronic and molecular structure in general. For many reasons, especially the need for brevity in an introductory paper, the field for consideration will have to be narrowed down so as to exclude a study of molecules in the solid state, as well as linkages comprised of multiple bonds, and to concentrate largely on complex ions and coordination compounds which contain only one central atom (mononuclear structures: MX_n).

The material that comprises this paper provides nothing that has escaped those who are thoroughly familiar with the field. But the paper does collect, select and coordinate a number of examples of electron-molecular relationships suitable for the writer's course in advanced inorganic chemistry given at the graduate level. A number of related topics will be made available through these pages, or those of the HORMONE.

That water is not a linear molecule is by now common knowledge to almost every Freshman. But that the structure $Ag(NH_3)_2^+$ is generally accepted as an essentially linear (2) structure is not equally well known. The following consideration serves to correlate these views. In general *p* orbitals have directional properties in space, tending to produce angular structures; but on the other hand an *s* orbital, of which there is only one in each of the principle energy levels of the atom, tends to produce linear structures, such as the argentammine ion already mentioned. For, directional indifference in the *s* orbital is so pronounced, that if the central atom of a three-atom, non-cyclic structure uses one *s* and one *p* orbital for bonding, the *s* orbital is flexible enough to get removed as far as possible from the potentially fixed *p* orbital so as to make the structure a linear one. On the other hand two *p* orbitals are fixed with reference to each other in space, thus accounting for many angular structures. The water molecule, using only the *p* orbitals of oxygen, is angular in shape; the argentammine cation, using one *s* and one *p* orbital of the silver ion, has a linear shape: N - Ag - N.

EXERCISE I. Compare and contrast the electronic structure of oxygen in the atom and in the water molecule. Predict the structure of water.

	1s	2s	$2p_X$	$2p_Y$	$2p_Z$
$_8O$	(:)	(:)	(:)	(.)	(.)
H_2O	(:)	(:)	(:)	(:)	(:)
Difference				(.)	(.)

Conclusion: Water shows p^2 bonding orbitals; hence its structure is angular.

EXERCISE II. Extend exercise I to a description of H_2S, $(CH_3)_2O$, $(C_2H_5)_2S$, $Ag(NH_3)_2^+$, and $ICl_2^=$.

EXERCISE III. Why cannot a discussion such as this be extended from covalent to ionic bonds, especially in solution?

One might add that *p* orbitals lie at right angles to each other along x, y, and z axes: see subscripts in exercise I. In hydrogen sulfide the angle is about 92°; in water, about 105°. Various reasons are given for this angular discrepancy. It might be that they reflect some common fundamental reason. The greater electronegativity of oxygen over sulfur leaves partial positive charges on the hydrogen atoms of water. The discrepancy is explained by the greater repulsion between greater values of like charge. On the other hand, the *p* orbitals in oxygen can be considered to have partial *s* character: another reason which is sometimes adduced. Note further that *sp* orbitals can be expected to occur in complex cations, since by ionization the *s* orbital is left open for coordination.

One might ask why the complete coordinating power of an atom is not always used to advantage. Why do Ag(I) and Cu(I) show a coordination number of two, while Cu(II), and in some cases Ag(II), show the coordination number four? In some instances steric hindrance provides the answer: the groups cannot be accommodated spatially about the central atom or ion (particle). The term "instability" is the thermodynamic answer, but without much of a picture. The stability, lent extrinsically to a compound, by chelation for example, seems to confirm this second reason in some instances. The oxidation state II in silver is unusual, but it is found in silver picolinate where the structure is stabilized by chelation. It can be argued that hydrates, otherwise unstable in the isolated condition, exist in solution because of the mass action effect of the solvent. The most fundamental restriction on coordination number is the availability of a sufficient number of orbitals for bonding. In the higher oxidation states, orbitals from lower levels are made available through the loss of electrons through oxidation.

Thus far we have been concerned with structures whose central atom has coordination number two. The reasoning can be extended to coordination number three without undue complication. Nitrogen and other elements in the fifth group, in their ammonia analogues, provide the simplest illustrations.

EXERCISE IV. Compare and contrast the electronic structure of nitrogen in the atom and in the ammonia molecule. Predict the structure of ammonia.

		1s	2s	$2p_X$	$2p_Y$	$2p_Z$
	$_7N$	(:)	(:)	(.)	(.)	(.)
	NH_3	(:)	(:)	(:)	(:)	(:)
Difference				(.)	(.)	(.)

Conclusion: Ammonia uses three of the *p* orbitals of the nitrogen for bonding (p^3 bonding); hence the three hydrogens lie at right angles to each other. The hydrogen atoms are thought to be spread out, however, by reason of mutual repulsion, somewhat analogous to that found in the water molecule.

EXERCISE V. In a similar way consider the ClF_3 structure. Compare your conclusions with those of Fessenden (*7*). Consider also the arsine and stibine structures.

Thus ammonia has the shape of a trigonal pyramid. It can be described as an irregular solid, resembling a tetrahedron with its nitrogen atom at the center, but bereft of apex above the nitrogen atom, and with a somewhat broader triangular base, which is defined by the three hydrogen atoms. In fine, the nitrogen atom does not lie in the plane of the hydrogen atoms.

Since there is only one *s* orbital in a given energy level, s^2, s^3 and s^2p bonding is meaningless; the use of sp^2 bonds is, however, possible. In such structures, the two *p* orbitals define a plane; the *s* orbital is free enough to fall into that plane; planar structures result. The borate, nitrate and carbonate ions provide examples of such structures, along with the halides of boron. Resonance in such structures complicates further discussion of them.

As a general rule (Hund) the *s* orbital is filled first and then each of the *p* orbitals gets its first electron in succession, so that each *p* orbital already contains one electron before a second one is added to any of them. It is not always possible to predict such orbital priority in more complicated cases, so that one may have to choose between many possibles. Obviously, recourse to experiment, the correlation of chemical data, electron diffraction, dipole and magnetic moment data and the like are called for.

Much of the stereochemistry of coordination number four brings us into the familiar realm of the organic chemistry of the saturated carbon compounds where tetrahedral structures prevail. In the following exercise, one has to distinguish between the basic energy state of the carbon atom sp^2 and the promoted state sp^3. The energy difference between these two states is said to be small and more than compensated for by the bonding energy in tetrahedral bonds.

EXERCISE VI. Compare and contrast the electronic structures of carbon in the atom and in methane. Show the orbital configuration which corresponds to the tetrahedral structure in this case.

	1s	2s	$2p_X$	$2p_Y$	$2p_Z$	
$_6C$	(:)	(:)	(.)	(.)	( )	Basic state.
$_6C$	(:)	(.)	(.)	(.)	(.)	Promoted state.
CH_4	(:)	(:)	(:)	(:)	(:)	
Difference		(.)	(.)	(.)	(.)	

Conclusion: sp^3 bonding is had. This corresponds to the tetrahedral structure.

It is to be noted that other types of bonding correspond to the tetrahedral structure. Irregular tetrahedra occur with d^2sp, dp^3 and d^3p bonding. Indeed there is reason to believe that irregular tetrahedra occur among the sp^3 linkages of organic chemistry where polar molecules such as $CHCl_3$ and the like are abundant.

EXERCISE VII. Compare and contrast the electronic structures of nitrogen in the atom and in the ammonium ion. What is the structure of the ammonium ion?

		1s	2s	$2p_X$	$2p_Y$	$2p_Z$
	$_7N$	(:)	(:)	(.)	(.)	(.)
	NH_4^+	(:)	(:)	(:)	(:)	(:)
Difference			(*)	(.)	(.)	(.)

*The *2s* orbital is used for coordinating the proton.

Conclusion: An *s* and three of the *p* orbitals are used for bonding. sp^3 bonding occurs. This corresponds to the tetrahedral structure. Substituted ammonium ions with an asymmetrical nitrogen atom will then exhibit optical isomerism.

EXERCISE VIII. In a similar way, discuss the hydronium ion.

The description of the ammonia molecule, given earlier, can be elucidated here. The two unoccupied *2s* electrons take on a proton by coordination to give the sp^3 tetrahedral structure of the ammonium ion. At the same time the other hydrogen atoms shift to take up the angles of a perfect tetrahedral structure.

In discussing the argentammine cation earlier, it was shown to be linear along the N - Ag - N axis. Now it can be readily seen that the complete structure corresponds to two tetrahedra which are aligned on this axis with the silver ion as the common apex. Likely the tetrahedra are irregular due to differences in N - H and N - Ag bond lengths.

It is well known that the strengths of *s* and *p* bonds differ. Still the fact has to be faced that each of the four valences of carbon are equivalent. A number of explanations have been adduced to reconcile these differences. Again each explanation must be based on some common fundamental reason.

The reason most commonly given is taken from Pauling (3). Quantum mechanical calculations indicate that the maximum bond strength is to be found in the so-called "hybridization" or "resonance" of the bond types among the four orbitals. Thus each of the orbitals has now largely *p* character with only lesser contribution of *s* character. In such a combination each of the four bonds is stronger than it would be alone in other structures, or conceivably in the same structure before hybridization might take place. One argues to the added bond strength as follows: Bond strengths would be given by the weighted average of the bond strengths of the types of bonds involved, or by the greatest bond strength, or by some even greater bond strength. Assigning potentially greater bond strength to the *p* orbital, then in the first case it would be less than its original value (whence the additional energy?); in the second case, *s* and *p* bonds would be identical; this leaves the third case. Pauling (3) assigns a value of unity to a potential bond from an *s* orbital; he calculates on this basis a bond strength of 1.732 for a *p* orbital and a maximum value of two for each of the hybridized sp^3 orbitals.

EXERCISE IX. Consult Pauling (3) and tabulate bond strengths for s, p and d orbitals, and compare with single bond strengths of the hybridized orbitals: sp^3, d^2sp and d^2sp^3.

One would expect that in the first case a p orbital would sooner retain its identity than lose in strength, from our knowledge of the dissipation of energy. The second case is contrary to fact. The third case finds good support in fact.

Another structure occurring with coordination number four is the square coplanar structure. It corresponds to dsp^2 orbitals. The commonest example is copper (II) tetrammine cation. One of the 3d electrons in copper is lost by ionization and the cupric ion is electronegative enough to engage four ammonia groups, each at one of the corners of a square plane. The less rigid d and s orbitals have relaxed into the plane fixed by the p orbitals. The rectangular figure is in this case stabler than the tetrahedral. Distortion of this plane by unsymmetrical substitution is again conceivable. The possibility of *cis* and *trans* isomerism (8) is immediately evident.

EXERCISE X. Suggest a structure for copper glycine. Reasons?

Coordination number five can conceivably find structural expression in either a planar pentagon, a pyramid (square base and apex) or a trigonal bipyramid (two tetrahedra-like structures with triangular base in common). The third of these is the most symmetrical and probably the most often encountered. For, other things being equal, the most symmetrical figure implies the one with the least potential energy or with the greatest bond energy. Pauling assigns this stucture to PCl_5.

EXERCISE XI. Give structures for BrF_5 and IF_5. See Fessenden (7).

EXERCISE XII. Work out the orbital arrangements for PCl_3 and PCl_5. Compare them.

Coordination number six is to be found in most of the transition elements. The hexa-coordinated compounds of iron cobalt and platinum are numerous and well-known. The cobalt (III) ammine ion is the commonest example. It is given by an octahedron (eight sides and six corners; two pyramids with square base in common). This structure is correlated with d^2sp^3 orbitals. Abundant isomerism is here possible (8).

EXERCISE XIII. A sample of reagent grade nickel salt is contaminated with spectroscopic amounts of cobalt which has to be removed before the "nickel" can be brought into contact with powerful neutron sources. Suggest a chemical method for the removal of cobalt.

So far we have provided an outline for the study of structures commonly encountered in chemical work. Indeed, from the early work of Pauling (3), Kimball (4) and others, calculations have been made for a great variety of combinations of *s*, *p* and *d* orbitals. With each of the resulting arrangements, a very definite molecular structure or stereochemical type has been correlated. Structural conclusions, drawn by Alfred Werner, early in this century, based on purely chemical evidence have found further support and verification. Many doubtful structures have been re-investigated at the instigation of this modern attack, and with the aid of modern physical methods have been definitely settled.

EXERCISE XIV. Consult the summaries of stable bond arrangements given by Kimball (4), Campbell (4) and Emeleus and Anderson (5).

EXERCISE XV. Using Fisher-Hirschfelder Models check a number of the foregoing structures.

It is well to note the relationship existing between square and octahedral complexes. The square complex is potentially octahedral and fails to achieve the latter configuration by default. Common to both is the square configuration of the common base to the two pyramids in the octahedron. Failure to use the fifth and sixth orbitals in the case of the square complex constitutes the default. Such orbitals might not be available in the ordinary stable levels of the atom, as in the case of copper and nickel. Still, external chelation might in cases supply the extra required stability for the higher energy levels. Again steric factors might prevent the use of these orbitals. In cases, greater stability in coordination number four might be supplied by the tetrahedral configuration, due to external principles of molecular architecture, such as the geometry of the ligand.

The interplay of two principles provides a general summary of the foregoing material. The first is the fact of the directional properties of *p* orbitals, as contrasted with the directional indifference of the *s*; and possibly of *d* orbitals. The second principle is that the most symmetrical or stable configuration will be produced. This interplay is primarily possible because the flexibility of the *s* orbital allows symmetrical or stable configurations to be produced. The more particular summary to follow bears this out.

1. If only *p* orbitals are used for bonding, angular structures result.

   Planar: H_2O, H_2S, NO_2, ClO_2; Solid: NH_3, SO_3, BrO_3, ClO_3.

2. Such structures are relaxed where the *s* orbital is involved.

   Linear: $Ag(NH_3)_2{}^+$, $Cu(NH_3)_2{}^+$; Planar: BF_3, $BO_3{}^{3+}$, $CO_3{}^=$, $NO_3{}^-$.

3. The use of dsp^2 orbitals correlates with coplanar square configurations.

$Cu(NH_3)_4^{++}$, $Ni(CN)_4^{=}$, $PdCl_4^{=}$, $PtCl_4^{=}$, $Cu(en)_2^{++}$, $CuCl_4^{=}$.

4. But the use of sp^3 orbitals produces tetrahedral configurations.

CH_4, CCl_4, $CHCl_3$, NH_4^+, ClO_4^-, PO_4^{-3}, $SO_4^{=}$, MnO_4^-, $SeO_4^{=}$, AsO_4^{-3}, $Cu(CN)_4^{-3}$, $Ni(CO)_4$, $Zn(NH_3)_4^{++}$, $Zn(en)_2^{++}$, $Cd(NH_3)_4^{++}$, $Cd(CN)_4^{=}$, $CdI_4^{=}$, $SnCl_4^{=}$. (See ref. 9).

5. The use of d^2sp^3 orbitals correlates with octahedral structures.

$Co(NH_3)_6^{+3}$, UF_6, IO_6, $PtCl_6^{=}$, $PdCl_6^{=}$, $Ni(NH_3)_6^{++}$, $Ni(en)_3^{++}$, $Cr(SCN)_6^{-3}$, AlF_6^{-3}.

Numerous other correlations have been made as exercise XIV will show; but those outlined above are considered the commonest and most important correlations.

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Mathematics

CONGRUENCES

JOHN GREEN, S.J.

In giving the hour of the day it is customary to count only up to 12 and then to begin over again. This simple idea of throwing away the multiples of a fixed number 12 is the basis of the arithmetical notion of congruence. Two integers are congruent "modulo 12" if they differ only by an integral multiple of 12. For example 7 and 19 are so congruent, that is $19 \equiv 7 \mod 12$.

Two "necessary and sufficient" theorems which concern congruences are:

1. Two integers a and b are congruent modulo m if and

only if they leave the same remainder when divided by m.

2. If the moduli m_1 and m_2 are relatively prime, then the congruences $x \equiv b_1 \bmod m_1$ and $x \equiv b_2 \bmod m_2$ have a common solution x. Any two solutions are congruent modulo $m_1 m_2$.

An interesting problem concerning congruences is the cocoanut problem. On a desert island, five men and a monkey gather cocoanuts all day then sleep. The first man awakens, and decides to take his share. He divides the cocoanuts into five equal shares with one cocoanut left over. He gives the extra one to the monkey, hides his share, and goes to sleep. Later the second man awakens and takes his fifth from the remaining pile; he too finds one extra and gives it to the monkey. Each of the remaining three men does likewise in turn. Find the minimum number of cocoanuts originally present. Elementary algebra is used to set up the equation. Let x equal the number of cocoanuts. The number of cocoanuts remaining in the pile after the first man has taken his share and given one to the monkey is $\frac{4}{5}(x-1)$. After the second man has taken his share and given one to the monkey there are $\frac{4}{5}[\frac{4}{5}(x-1)-1]$ cocoanuts left and so on until the five men have taken their shares, when the final equation is $\frac{4}{5}(\frac{4}{5}[\frac{4}{5}(\frac{4}{5}[\frac{4}{5}(x-1)-1]-1)-1]-1)$. When the parentheses are re-removed the resulting equation is $\frac{1024x-8404}{3125}$ which is the congruence $1024x \equiv 8404 \bmod 3125$. Solving for x after reducing the congruence the result is $x = 3121 + 3125k$ where k runs from 0 to infinity. Since the minimum number of cocoanuts was desired, k is put equal to 0. Therefore the required number of cocoanuts is 3121.

This problem can be expanded to include any number of men gathering cocoanuts and then taking their share with the monkey receiving the extra cocoanut. For three men the congruence is $8x \equiv 38 \bmod 27$ and x equals 25 plus 27k. For four men the congruence is $81x \equiv 525 \bmod 256$ and x equals 253 plus 256k. The congruence for six men is $15625x \equiv 201811 \bmod 46656$ and x equals 46651 plus 46656k. For n men under the same conditions x equals $n^n-(n-1)$ plus $n^n k$.

Simultaneous congruences in one unknown with different moduli can be solved by the aid of the following theorems:

1. A necessary and sufficient condition in order that congruences $x \equiv a_1 \bmod m_1$, $x \equiv a_2 \bmod m_2$, ... $x \equiv a_n \bmod m_n$ have a common solution is that $(mi, mj) \mid a_i - a_j$ $i \neq j$. There is then just one solution in the interval $0 \leqq x < [m_1, m_2, ..., m_n]$.
2. If every pair of moduli m_i, m_j consists of relatively prime numbers, the system of congruences $x \equiv a_1 \bmod m_1$, $x \equiv a_2 \bmod m_2$, $x \equiv a_3 \bmod m_3$ . . . $x \equiv a_n \bmod m_n$ has a unique solution mod $m_1, m_2, . . . m_n$.

An example of a simultaneous congruence in one unknown with three different moduli is the following problem. A band of 13 pirates obtained a certain number of gold coins. They tried to distribute them equitably, but found they had 8 left. Two pirates died of smallpox; then after distributing the coins there were 3 left. Thereupon they shot 3 more pirates, but still there was a remainder of 5 coins. Find the minimum number of coins originally present. The three congruences are: $x \equiv 8 \bmod 13$, $x \equiv 3 \bmod 11$, $x \equiv 5 \bmod 8$. The solution of the first two congruences is $x = 47 + 143\, k$. Substituting this value of x in the third congruence the result is $x = 333 + 1144k$. Since the minimum number of coins was desired, k is put equal to zero and so there were 333 gold coins originally present.

A practical secret code makes use of congruences. The key consists of a matrix such as:

$$\begin{bmatrix} 2 & 1 & -1 \\ 3 & -2 & 1 \\ 1 & 2 & -3 \end{bmatrix} \bmod 29$$

and a correspondence such as a b c ..... z
1 2 3 .....26.

The word "victor" may be put into code as follows. By the correspondence "victor" corresponds to 22, 9, 3, 20, 15, 18. Set $x = 22$, $y = 9$, $z = 3$, and substitute into the congruences determined by the key matrix. These give

$$2x + y - z \equiv 21 \bmod 29$$
$$3x - 2y + z \equiv 22 \bmod 29$$
$$x + 2y - 3z \equiv 2 \bmod 29$$

Similarly the next three numbers, $x = 20$, $y = 15$, $z = 18$ give 8, 19, 25. The code message is "uvbhsy".

Physics

SEMICONDUCTORS

J. J. Ruddick, S.J.

Transistor-equipped radio transmitters that can be held in one's hand, hearing aid sets that are smaller than ever but use so little power that batteries can last for six months—these are recent announcements that have stimulated public interest in transistors and in the semiconductor materials of which they are made. For a study of transistors to be very profitable it is essential to have some knowledge of the semiconducting properties responsible for their action.

Although experimental investigations of semiconductors, especially with regard to their conductivity, had been done in the earlier part of the present century, it was 1931 before Wilson (1) gave the first approach to a theoretical explanation, and it was World War II before really extensive work was done on many of the aspects of semiconductors (2). The crystal set of early radio days used a metal point contact to a semiconductor to produce the rectification of the radio signals. However vacuum tubes soon superseded the crystal rectifiers and it was only with the development of high frequency radar that the crystal came into its own again. At the present it bids fair to replace many of the types of vacuum tube.

Among the solids semiconductors are not always a clearly dist'nct group. In general they are substances with a lower electronic conductivity than metals, with practically no ionic conductivity, and with a conductivity that *increases* with temperature.

The band approximation provides a means of discriminating between the three groups of solids that are distinguished by their conductivity. A *metal* is a substance with a partly filled conduction band. Because of the unoccupied energy states, an applied electric field can shift electrons from their original states to nearby ones, thus producing conduction. On the other hand, an *insulator* is a material with a filled valence band and an empty conduction band, the bands being separated by a "forbidden" band of several electron volts. Since high temperatures raise the energy of electrons only small fractions of an electron volt (kT is 0.025 ev at room temperature), an energy gap of the order of an electron volt effectively prevents conduction. That is, there are no empty energy states in the filled band, while the empty states in the conduction band are too far away for the electron to reach when under the influence of an applied field. The third group, that of substances with a low conductivity that increases with temperature, is divided into two subgroups. *Intrinsic semiconductors* are substances which have only a narrow forbidden band between the filled valence band and the empty conduction band. An increase of temperature is thus able to increase the conductivity by providing electrons with enough energy to cross the forbidden band. The second subgroup is that of *impurity semiconductors*. (See Fig. 1.) Due either to lattice defects in the crystal or to the presence of impurity atoms, such substances have either or both of the following situations: 1. Occupied levels are within the gap and only a small distance below the conduction band. Unoccupied levels are located slightly above the filled band. Thus the conductivity of the substance can be changed by the raising of electrons from the occupied levels to the conduction band, or by the raising of electrons from the filled band to the unoccupied levels. In this last case, the departure of the electron from the filled band leaves a "hole." Since an electron of another energy state in the band may now occupy the empty place, with the hole thus going to the newly vacated level, and so on, this mechanism gives rise to a change of conductivity ascribed to "hole conduction" in a given direction, in reference to the travel of electrons in the opposite direction. A hole has a positive charge and a negative mass of the same absolute magnitudes as an electron. The negative mass is, of course, due to the fact that in a gravitational field, electrons would move downwards and thus the corresponding holes would move upwards.

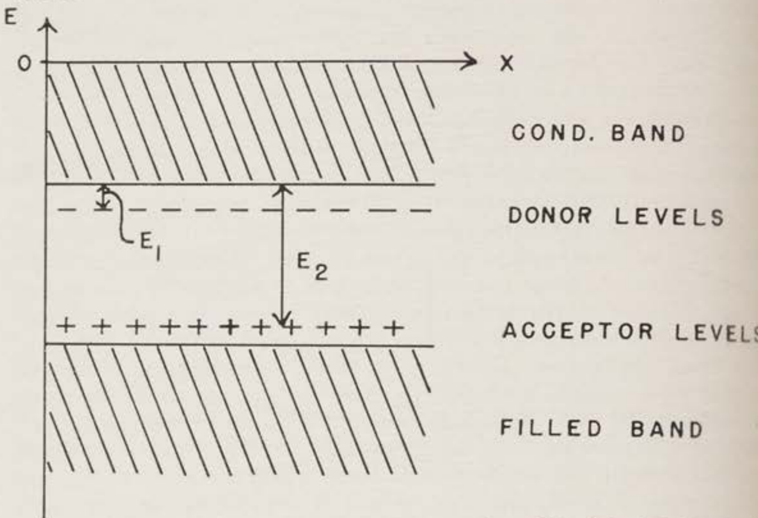

FIG. 1. Energy diagram for a semiconductor. The width of the forbidden band is of the order of an electron volt for extrinsic semiconductors. Electrons may jump from the donor levels into the conduction band or from the filled band into the (empty) acceptor levels.

If the conduction is due to the raising of electrons from occupied levels to the conduction band, the current carriers are negative and the conduction is said to be n-type. If it is due to the motion of holes, it is called p-type (for positive). It is to be noted that for intrinsic semiconductors, for every electron raised all the way across the forbidden zone there will be a hole in the filled band. Hence there will be both p-type and n-type conduction at the same time.

What is a more pictorial way of looking at the donor and acceptor impurity levels? Consider the source of the levels in the energy gap. If, for instance, the crystal is germanium, neighboring atoms are bound together with a double bond structure. Each of the four valence electrons of a given Ge atom joins with a similar electron from a neighboring atom. These bonds are thus parts of a tight structure. If an atom of arsenic with five electrons available for bonding is substituted for a Ge atom, the bond structure leaves one electron free of a bond to a neighboring atom. This electron is thus free to wander about the lattice. Although it is held to the As nucleus by the electrical force of attraction, the effect of the dielectric constant of the Ge is to weaken that force, thus enabling thermal agitation to move the electron to moderate distances. Such "excess" electrons are the source of the donor levels mentioned above. A three-valence atom such as boron would, on the other hand, leave an empty bond-space which could be filled by an electron from some other bond. This second space could be filled from a third bond, and so on, with an equivalent positive charge moving in the opposite direction to the electron jumps. If there is no applied electric field, both the electron and the hole motion will be random. But if an electric field is applied, the electrons and holes will carry current across the crystal. It is reasonable to expect that the mobility of the holes should be about the same as that of the electrons. However, experimental results show that, while they are of the same order of magnitude, they do differ, the mobility of electrons in Ge being about twice that of holes (3).

It is in the determination of mobilities that the Hall effect has been so prominent. Since the Hall voltage (corresponding to the displacement of current lines in a magnetic field) depends on the reciprocal of the density of carriers, semiconductors give a more readily studied effect than the high carrier density metals. When taken in conjunction with conductivity measurements, Hall voltages can be used for determining mobilities and types of carriers.

Semiconductor physics is so complex that no theory has been developed for a direct and simple handling of its many problems. Nevertheless, for experimental work and preliminary analyses, the model of Fig. 1 has been well established. It seems destined to be the basis of whatever final theory is developed.

As for experimental problems, they are many and widespread. The approach to their solution has been both intensive, as in the detailed study of the properties of Ge by groups at Purdue and at the Bell Telephone Laboratories, and extensive, as in the many studies of oxide semiconductors at various university and industrial laboratories.

Fig. 1 is particularly apt as a foil for an examination of some of the experimental work now being done. Although not showing the work on transistors and on the action of p-n junctions, it does give some idea of the ways of studying semiconductors.

Photoconductivity experiments can give values for E_1 since the threshold for photoconductivity would represent the energy needed to get an electron from the donor level to the conduction band. A typical value for this quantity, for BaSrO, is 0.3 ev. Similarly cathodoluminescence studies can give values for levels and level densities. The mechanism for this is the excitation of electrons in the semiconductor by electrons from an electron gun, with subsequent jumping of the electrons from the conduction band into either vacant donor positions or acceptor positions. Each energy jump has, of course, its characteristic luminescent wavelength which can be measured by a photomultiplier or other means. A combination of this method and a study of the variation of photoemission work functions can be applied to the determination of E_2 of Fig. 1. For oxide cathodes E_2 is found to be about an electron volt. Furthermore, photoemission studies, combined with a process, such as an increase of temperature, to get electrons just into the bottom of the conduction band, provides estimates of electron affinities. (The electron affinity is the energy necessary to free an electron to infinity from the bottom of the conduction band.) Also of interest are the depths of trapping centers in the semiconductor. Traps, for electrons, are acceptors which intercept the particles which are moving, say, in an applied electric field. By studying the trapping time and by illuminating the crystal with light of various wavelengths, the experimenter can obtain good estimates of the depths (or energy of binding) of the traps. It is the traps that produce the difference between drift mobility, the time average velocity per unit field, and microscopic mobility, the velocity per unit field at which the particle actually travels when moving. In the past much of the information on mobilities came from indirect measurements made in terms of the Hall effect. Recently, however, Haynes and Shockley have developed a direct method of measuring mobilities (3).

The temperature variations of the above and other properties are significant, as are the variations due to varying percentages of impurities. Other work of considerable importance for the study of oxide-coated cathodes is that dealing with the influence of the base metal on the properties of the semiconductor. Similarly of interest is the most efficient proportion of Ba to Sr in the BaSrO semiconductors and the effect on emission of small amounts of Ca, which seems to act as a "catalytic" agent for emission. The "pore conduction" theory advanced by Loosjes and Vink (4) to explain varying conductivities in oxide emitters may also prove to be a source of simplification of the complexities of experimental data on that type of semiconductor.

For the relatively pure semiconducting materials such as Ge and Si, work of great importance is being done on transistors. These are devices which can give power gains of up to 100 by the proper application of a set of electrodes to semiconducting crystals. After only six years they are now being used in the place of triodes in many types of electronic circuit, especially where noise can be tolerated (5).

In summary: Vast amounts of experimental data have been gathered in the past decade, all agreeing with the basic model of a semiconductor as an insulator with donor and/or acceptor levels in the forbidden gap between the filled and conduction bands. Nevertheless, this material has not yet led to a unified, clear theory that explains the various effects. Many facets of the subject are currently developing, but the general theory, if there is one, is still in the future.

References

1. Wilson, *Proc. Roy. Soc.*, **133**, 458 (1931).
2. A good summary of the basic theory of semiconductors and crystal rectification is given in Part II of the Radiation Lab volume *Crystal Rectifiers* by Torrey and Whitmer. New York: McGraw-Hill (1948).

3. Haynes and Shockley, *Phys. Rev.*, **81**, 835 (1951): electrons and holes have mobilities of 3600 and 1700 cm^2/v-sec, respectively.
4. Loosjes and Vink, *Philips Res. Repts.*, **4**, 449 (1949).
5. For descriptions and theory of transistors see Shockley's *Electrons and Holes in Semiconductors*. New York: Van Nostrand (1950). A recent article on junction transistors is that of Sparks in *Scientific American* for July, 1952. On circuit design see Raisbeck, *Electronics*, **24**, 128 (1951).

News Items

The first issue of *Catholic Science Notes* announces the proposed organization of a Catholic Science Organization to replace the Catholic Round Table of Science. The new organization will be under the auspices of the National Catholic Educational Association. The board of editors of the *Notes* includes Father John A. Tobin, S.J., of Boston College, and Father Patrick H. Yancey, S.J., of Spring Hill. The editors are anxious to obtain the names of interested Catholic scientists, especially those teaching in non-Catholic schools, and to obtain comments on the desirability and the nature of the proposed organization and its publication. Those interested in having their names added to the mailing list for the *Science Notes* should write to:

Catholic Science Notes
National Catholic Educational Association
1785 Massachusetts Ave., N.W.
Washington, 6, D.C.

HOLY CROSS COLLEGE—CHEMISTRY DEPARTMENT

Father Joseph A. Martus, S.J., received the Ph.D. degree in Chemistry from Clark University in June 1952. On the resignation of Prof. C. B. Murphy, who received the Ph.D. from Clark at the same time, Father Martus took over his place in the department. This now makes four out of six staff members in the department who hold the doctorate in chemistry: Profs. Baril, Fiekers, Martus and VanHook. This year Mr. Paul J. McCarthy, S.J., Holy Cross M.S. '52, of the Province of New York, S.J., started under Dr. Martell at Clark University his work toward the Ph.D. degree (chelation). Indeed it has been estimated that twelve alumni who have received the bachelor's degree in chemistry over the last five years became engaged in graduate work for the Ph.D. degree and that over half of these achieved the degree thus far; that in addition nine who have received the Master's degree here, based on undergraduate work elsewhere, are or have been similarly engaged; and that, extending the survey beyond alumni of the past five years, so as to include late starters in doctorate work, there is a total of twenty-seven men now engaged in that work. Their universities include Brown, Clark, Columbia, Connecticut, Cornell, Maryland, Massachusetts State, Notre Dame, Penn. State, Pittsburgh, Princeton, Rennselaer and Yale. This is a fair showing, when one considers that we graduate from ten to fifteen bachelors in chemistry each year and that a goodly proportion is lost to the Armed Forces, especially through the R.O.T.C. training programs.

We are happy to announce that Father Martus' grant for work on Chelation from the Ordnance Department has been renewed for the coming year. Prof. VanHook has received a two-year grant from the Department of Agriculture for work on the Crystallization of Sugar.

On invitation, Prof. VanHook took a flying trip to Brussels, Belgium and Malmo, Sweden, during the latter part of February to address International Sugar Conferences on this favorite topic.

Father Fiekers held the chairmanship of the Central Massachusetts Section of the American Chemical Society during the term 1952-1953, based on having been Chairman-Elect and Chairman of the Program Committee during the previous year, and with the prospect of becoming automatically a Councillor of the Worcester Engineering Society for the ensuing year. Father Martus directed public relations for the Section; Prof. Baril was a councillor; and Prof. VanHook chairmanned the Manpower Committee. The College was host to the Section for a number of meetings during the year, especially mentionable is "Students' Night" on the evening of April 18th, 1953, to which all High School and College Chemistry Students of Worcester County were invited. Attendance exceeded one hundred and fifty and included some older members of the section. Other extra-curricular activities include Father Martus' chairmanning the Central Section of the New England Association of Chemistry Teachers for the term 1952-1954; the fact that Father Martus and Prof. Baril were judges in the Rhode Island Science Fair, held in Providence in early March; and that Fathers Fiekers and Martus did similar service for the Massachusetts Science Fair in Boston in April.

Within the department, Father Martus is Moderator of the CROSS & CRUCIBLE Chemists' Club, Chapter of Student Affiliates of the American Chemical Society, and Father Fiekers is Moderator of the Student Publication, the HORMONE.

For years Prof. VanHook has been an abstractor for CHEMICAL ABSTRACTS. Recently Father Fiekers joined the ranks of this service to the profession. Recent departmental publications include the following: A. VanHook and E. J. Reardon, Liesegang Rings on Metallic Bases, Nature, *171*, 177 (1953); A. VanHook and F. Frulla, Nucleation in Sucrose Solutions, Ind. Eng. Chem., *44*, 1305-8 (1952); R. K. Himmelsbach, A Technique for Hot Filtrations, Chemist Analyst, *41*, 35-8 (1952); A. VanHook and E. J. Kilmartin, S.J., The Surface Energy of Sucrose, Z. Elektrochemie, 56, 302-5 (1952);

and A. VanHook and W. F. Biggins, Surface Tensions of Pure and Impure Sugar Solutions, Internat. Sugar J., 54, 7-10 (1952).

New equipment in the department includes a demonstration Geiger Counter, a Gow-Mac apparatus for measuring Gas Conductivity, a new utility hood, battery eliminators, eighteen stirring motors converted from War Surplus to be stocked in the desks of the students in the course of Advanced Organic Chemistry, and, as a gesture to good housekeeping, eight Taylor Indicating Thermometers have been permanently installed in drying ovens around the department. In addition we have on loan from the government two Beckman, Model G, pH meters and a Monroe Calculating Machine.

BOSTON COLLEGE — SEISMOLOGICAL OBSERVATORY

During the month of May, Fr. Linehan gave lectures to the Cardinal O'Connell Council, Knights of Columbus, at St. Ignatius Church; to the Holy Name Society at St. Angela's, Mattapan; the Sodality of the Blessed Virgin at Lewiston, Maine; a Chapel Talk to the students at Bates College, under the auspices of the Newman Club; the Everett Rotary Club; and, in June, preached at the First Solemn Mass of Fr. Richard Philbin in Clinton. Thus, a fairly heavy lecture schedule for the year 1952-1953 was completed. Nothing more until the autumn, excepting several papers before scientific Societies.

Several seismic field problems occupied the staff during May and June. One in Natick for rock soundings to assist the M.D.C. in designing a Trunk Sewer Line in that area; two others concerning foundations for Churches, one the Immaculate Conception in Worcester and the other, St. Bridget's in Millbury. Two building foundation studies took the staff far afield. The first, in Connecticut, also gave the opportunity for the priest member of the group to give the last rites to an injured person on the Merritt Parkway. Seismology certainly helped that person. The second building problem brought us to Montreal where we made studies for the College Ste. Marie, the oldest Jesuit College in Canada. Seismic studies for water supplies were made in Bristol, Connecticut, for the Bristol Brass Company; and foundation studies were made for the Cole Trucking Company in Worcester.

We have begun some geological reconnaissance mapping in Scituate in preparation for possible later seismic studies for water supplies; likewise, Mr. Skehan brought members of the geology class to map the geologic structure at the Mass. Broken Stone quarries in Weston. This is a new application of geology we have been introducing to the local Quarry Industry that quarry managers may plan their method of blasting to obtain material of certain physical properties.

Our perpetual benefactor, Mr. Richard Robinson of Weston, has just added another gift in the form of a garage building. It was designed by Mr. William A. Shea of Wellesley, and constructed by Mr. Robinson's craftsmen. This building will house all of our mobile equipment, both trucks and field apparatus. The building is placed to the north of the present Observatory and is white with green trim to match the earlier building Mr. Robinson gave us. This latter building is used for dead storage. A wide black-topped driveway completes the picture, and this drive encircles the new building.

During May, plans were completed to work with the Gahagan Construction Corp., of New York, N. Y. This company has been engaged in heavy construction work and deep water dredging for some years and recently desired to add geophysical research to their work to assist themselves and to render aid to other engineering groups. At present, Fr. Linehan and Dr. Slotnick of Houston, Texas, are retained as consultants, and an instrument operator with assistant, and a secretary are based at the observatory. A new mobile unit with the latest refraction and reflection equipment and a station wagon belonging to the Gahagan Construction Corp. are housed at the Observatory. This arrangement will permit far more research opportunities in various types of field work than was possible in the past.

During the spring several hundred trees were planted to take the place of the dead oaks that were felled a year ago. The heavy spring rains have given these a goodly start in arboreal life. Brother Monahan directed the planting of these trees.

The Geophysics Division of the Air Force has taken some space in the Observatory for a few months to conduct tests on new equipment of their design. Our summer school classes contain four students, one of whom is Fr. Gouin, who has returned from tertianship to complete his thesis assignment. Fr. Buist, S. J., of Breboeuf College, Montreal, is here for the summer to acquaint himself with reading records. Breboeuf College is to open a seismic station this year.

Mr. James W. Skehan, S. J., received his Doctorate in Geology from Harvard University in June.