careful workers but without much imagination or drive, be allowed to scan a list of scientific subjects soon after graduation and select one at random, to nobody's benefit and for an indefinite period? If the individual is working in a purely academic post, obviously yes, though he probably will not last long in a university if he is a gamma minus. You will say that it is impossible to predict in what way scientific research may prove of practical importance. Though this may be true as regards the good scientists, it is very unlikely that the work of a gamma minus on, let us say, the morphology of fossil fish, will prove to be of great value scientifically or practically. May there perhaps be a reason, particularly in a country like Great Britain, where there is a severe shortage of scientific manpower and material, for directing such a person's work into lines believed to be profitable?

This is not the view that the Agricultural Research Council has adopted, far from it; but sooner or later it is a problem that the research councils in England will have to face. For the moment you use the taxpayer's money you have the responsibility of using the funds to the best advantage of the taxpayer. It may be asked, "Why use the taxpayer's money at all?" There are, I believe, two reasons. First, because, in my opinion, private benefactors will not be able to continue subsidizing scientific research in this modern world for much longer; they just will not have enough money. Secondly, I believe that ten of the best scientists in Great Britain can put money to better scientific use than one individual, who, more often than not, is a layman.

As regards what I call the good scientists, there is no problem. We believe in giving them the same freedom in their work that they would have in a university department, not only because their work will be worth while, but because they will attract other scientists, who may have somewhat different leanings, into agricultural research. Scientifically speaking, agriculture is in a rather depressed state in the United Kingdom. The really bright young man in the past has rarely gone in for agriculture, and on the basis of a few conversations I have had with experts in the United States, I believe the same situation exists here. A distinguished scientist with deep agricultural interests told me the other day that the dice were loaded, at any rate until very recently, against an agricultural scientist in America becoming a member of the National Academy of Sciences. I believe that the solution of this problem in England, and also in this country if it exists, depends on getting scientists working in the basic sciences into agriculture after they have graduated rather than by trying to persuade them to study agriculture as a degree subject. If I were chairman of an American Agricultural Research Council, I should spend a good deal of time trying to persuade leading established scientists to put young scientists onto problems of interest to *them*, rather than on problems of interest to agricultural research, on behalf of an American Agricultural Research Council. By this method I should hope to get a nucleus of really first-class young research men working for the Council; I think that this policy would pay handsome dividends.

HOW NEWTON DISCOVERED THE LAW OF GRAVITATION

By JAMES E. MILLER

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A tremendous increase in the number of vigorous young workers in the scientific vineyard has been one of the happiest results of the recent expansion, encouraged and nourished by our Federal Government, of scientific research in

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this country. These neophytes, left to their own devices by harassed research directors, have often found themselves without adequate guidance through the intricacies of governmental sponsorship; but, fortunately, they can find inspiration in the story of Sir Isaac Newton, his development of the law of gravitation, and his experiences as director of the Subproject for Apples of the Fruit-Improvement Project, sponsored by His Majesty's Government of Great Britain in cooperation with a syndicate of British fruit-growers.

Few are familiar with the details of Newton's twenty-year search for a proof of his hypothesis: the frustrations and failures, the need for accurate measurements of the earth's radius and for a mathematical tool that Newton himself was forced to invent, and the integration of his scattered efforts by the splendid organization of the Fruit-Improvement Project. These details have been collected from his *Principia*, personal letters, notebooks and other papers, and a series of personal interviews arranged by a medium of the author's acquaintance.

In 1665 the young Newton became a professor of mathematics in the University of Cambridge, his alma mater. His devotion to his work and his capabilities as a teacher and friend of the student may be assumed without question. It is well to point out also that he was no dreamy, impractical inhabitant of an ivory tower. His services to his college went far beyond the mere act of classroom teaching. He was an able and active member of the college's curriculum committee, the board of the college branch of the Young Noblemen's Christian Association, the dean's advisory committee on scholarships and awards, the committee for discipline, the grounds committee, the publications committee, the ad hoc committee, and numerous other committees essential to the proper administration of a college in the seventeenth century. An exhaustive compilation of Newton's work along these lines reveals that, during a five-year period, he served on 379 committees, which investigated an aggregate of 7924 problems of campus life and solved 31 of them.

Newton the genius was yet a human being; and though, in energy and ability, he far surpassed the great majority of his fellow men, he found himself ultimately limited in his powers. His unselfish devotion to the important work of his committees absorbed so much time that he was constrained to turn more and more of his teaching duties over to one of his students. He reasoned, quite correctly, that the substitution of a student as teacher in his place would benefit both the student and the student's students: the former because, in teaching, his own knowledge would be enhanced; and the latter because, in being taught by one near to them in age and interests, they would more eagerly grasp at the scraps of knowledge that came their way. Newton, whose stipend was small, did not spoil this idyllic arrangement by offering pay to his student substitute: a prime example of his sense of values and his restraint. Eventually, when his substitute had proved his ability as a teacher, Newton turned all of the classroom work over to him and was thus able to channel all his tremendous powers into the administrative work of the college.

At about this time Newton, whose mind was too active ever to let scientific problems recede from his attention, occasionally mulled over the great discoveries of Kepler on planetary motions and the hypothesis, advanced by a number of astronomers, that these motions were governed by an attraction that varied inversely as the square of the distance between planets. One evening of a crowded day in the year 1680, a committee that was scheduled to meet at eleven o'clock, no earlier time being available, was unable to muster a quorum because of the sudden death from exhaustion of one of the older committee members. Every waking moment of Newton's time was so carefully budgeted that he found himself with nothing to do until the next com-

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mittee meeting at midnight. So he took a walk—a brief stroll that altered the history of the world.

It was on this excursion into the night air of Cambridge that Newton was struck by a flash of insight which set off a chain of events culminating in his announcement of the law of gravitation to the world in 1686. The season was autumn. Many of the good citizens in the neighborhood of the modest Newton home had apple trees growing in their gardens, and the trees were laden with ripe fruit ready for the picking. Newton chanced to see a particularly succulent apple fall to the ground. His immediate reaction was typical of the human side of this great genius. He climbed over the garden wall, slipped the apple into his pocket, and climbed out again. As soon as he had passed well beyond that particular garden, he removed the apple from his pocket and began munching it. Then came inspiration. Without prelude of conscious thought or logical process of reasoning, there was suddenly formed in his brain the idea that the falling of an apple and the motions of planets in their orbits may be governed by the same universal law. Before he had finished eating the apple and discarded the core, Newton had formulated his hypothesis of the universal law of gravitation. By then it was three minutes before midnight, so he hurried off to the meeting of the Committee to Combat Opium Eating Among Students Without Nobility.

In the following weeks Newton's thoughts turned again and again to his hypothesis. Rare moments snatched between the adjournment of one committee and the call to order of another were filled with the formulation of plans for testing the hypothesis. Eventually, after several years during which, according to evidence revealed by diligent research, he was able to spend 63 minutes and 28 seconds on his plans. Newton realized that the proof of his hypothesis would take more spare time than might become available during the rest of his life. He had to find accurate measurements of a degree of latitude on the earth's surface, and he had to invent the calculus.

Finally he concluded that he must find some relief from his collegiate administrative burdens. He knew that it was possible to get the King's support for a worthy research project of definite aims, provided a guarantee could be made that the project would be concluded in a definite time at a cost exactly equal to the amount stipulated when the project was undertaken. Lacking experience in these matters he adopted a commendably simple approach and wrote a short letter of 22 words to King Charles, outlining his hypothesis and pointing out its far-reaching implications if it should prove to be correct. It is not known whether the King ever saw this letter, and he may not have, being overwhelmed with problems of state and plans for pending wars. There is no doubt that the letter was forwarded, through channels, to all heads of departments, their assistants, and their assistants' assistants, who might have reason to make comments or recommendations.

Eventually, Newton's letter and the bulky file of comments it had gathered on its travels reached the office of the secretary of HMPBRD/CINI/SSNBI—His Majesty's Planning Board for Research and Development, Committee for Investigation of New Ideas, Subcommittee for Suppression of Non-British Ideas. The secretary immediately recognized its importance and brought it before the subcommittee, which voted to ask Newton to testify before the Committee for Investigation of New Ideas. Some discussion of Newton's idea—as to whether it could really be called British in intent—preceded this decision, but the transcript of the discussion, filling several quarto volumes, clearly shows that no real suspicion ever fell upon him.

Newton's testimony before HMPBRD/CINI is recommended to all young scientists who may wonder how they will comport themselves when their

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time comes. His college considerately granted him two months' leave without pay while he was before the committee, and the Dean of Research sent him off with a joking admonition not to come back without a fat contract. The committee hearing was open to the public and was well attended, though it has been suggested that many of the audience had mistaken the hearing room of HMPBRD/CINI for that of HMCEVAUC—His Majesty's Committee for the Exposure of Vice Among the Upper Classes.

After Newton was sworn to tell the truth and had denied that he was a member of His Majesty's Loyal Opposition, had ever written any lewd books, had traveled in Russia, or had seduced any milkmaids, he was asked to outline his proposal. In a beautifully simple and crystal-clear ten-minute speech, delivered extemporaneously, Newton explained Kepler's laws and his own hypothesis, suggested by the chance sight of an apple's fall. At this point one of the committee members, an imposing fellow, a dynamic man of action, demanded to know if Newton had a means of improving the breed of apples grown in England. Newton began to explain that the apple was not an essential part of his hypothesis, but he was interrupted by a number of committee members, all speaking at once in favor of a project to improve apples. This discussion continued for several weeks, while Newton sat in characteristic dignity waiting until the committee wished to consult him. One day he arrived a few minutes late and found the door locked. He knocked circumspectly, not wishing to disturb the committee's deliberations. The door was opened by a guard who told him there was no more room and sent him away. Newton, with his logical way of reasoning, deduced that the committee did not wish to consult him further, and forthwith he returned to his college and his important committee work.

Several months later Newton was surprised to receive a bulky package from HMPBRD/CINI. He opened the package and found it contained a variety of governmental forms, each in quintuplicate. His natural curiosity, the main attribute of the true scientist, provoked him into a careful study of the forms. After some time he concluded that he was being invited to submit a bid for a contract for a research project on the relationship between breed, quality, and rate of fall of apples. The ultimate purpose of the project, he read, was to develop an apple that not only tasted good but also fell so gently that it was not bruised by striking the ground. Now, of course, this was not what Newton had had in mind when he had written his letter to the King. But he was a practical man and he realized that, in carrying out the proposed project, he could very well test his hypothesis as a sort of side-line or by-product. Thus, he could promote the interests of the King and do his little bit for science in the bargain.

Having made his decision, Newton began filling out the forms without further hesitation. One of the questionnaires asked how the funds allotted for the project were to be spent. Newton was somewhat taken aback to read that £12,750 6*s*. 3*d*., the surplus remaining in the horticultural development fund for the current fiscal year, had been estimated as the total cost of his project. Methodically, he put down his own stipend first, and after a moment's thought he added the item: "Other salaries, travel, supplies, and overhead: £12,750 0*s*. 0*d*."

A true believer in correct administrative procedures, Newton sent the completed forms by special messenger to the Dean of Research, for transmittal through proper channels to HMPBRD/CINI. His adherence to established procedure was rewarded a few days later when the Dean of Research summoned him and outlined a new plan, broader in scope and more sweeping in its conception. The Dean pointed out that not only apples, but also cherries, oranges, lemons, and limes fell to the

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earth, and while they were about it they might as well obtain a real, man-sized government contract to cover all the varieties of fruit that grow above the ground. Newton started to explain the misunderstanding about the apples but he stopped rather than interrupt the Dean, who was outlining a series of conferences he proposed to organize among fruit-growers and representatives of various departments of His Majesty's Government. The Dean's eyes began to glaze as he talked, and he became unaware that anybody else was in the room. Newton had an important committee meeting at that time, so he quietly went out the door, leaving the Dean of Research in an ecstasy of planning.

The seasons passed, while Newton led a busy, useful life as a member of many committees and chairman of some. One dark winter's day he was called again to the office of the Dean of Research. The Dean was beaming; he proudly explained to Newton all about the new contract he had obtained to study the relationship between breed, quality, and rate of fall of all the varieties of fruit that grow above the ground. The project was to be supported by no less than five different branches of His Majesty's Government plus a syndicate of seven large fruit-growers. Newton's part in the project was to be small but important: he was to direct the Subproject for Apples.

The following weeks were busy ones for Newton. Though relieved from his committee work (a young instructor of Greek, Latin, history, and manual training took his place on the committees), he found himself cast into a morass of administrative problems: forms to be filled out for the governmental departments, for the fruit-growers, for the Dean of Research, for the Assistant Dean of Research, and for the financial office of the college; prospective research assistants to be interviewed and hired; office and laboratory space to be wangled from other projects on the campus. The wide abilities of our great genius are fully demonstrated by the way he piloted his subproject during its first formative weeks. He personally filled out 7852 forms, often in quintuplicate and sextuplicate; he interviewed 306 milkmaids and hired 110 of them as technical assistants. With his own hands he cleaned out an abandoned dungeon in a nearby castle for use as subproject headquarters; and, turning carpenter in typically versatile fashion, he erected twelve temporary buildings to house his staff. These buildings, used today as classrooms, stand as a monument to Newton's career.

Soon the subproject was fully implemented, documented, and regimented. Newton was not quite sure what his reconverted milkmaids could do for his hypothesis (he was a lifelong bachelor and hence not well acquainted with the ways of women), but he abhorred the thought of idleness in his staff. So he divided them into six teams, each of which was to measure and tabulate the rate of fall of one variety of apple, using sufficient apples to establish a statistically significant result. All went well except with the winesap team, who discovered a new way of making applejack, and consequently ran short of apples. Newton made a note of their recipe, wisely comprehending long before his fellow scientists the advantages of serendipity, or finding good things while looking for other things.

This period of his life was a happy and profitable one for Newton. From the time he arose in the morning until, exhausted with honest labor, he dropped late at night back into his humble bed of straw, he spent each day filling out payroll forms for his milkmaids, ordering pens and paper, answering the questions of the financial office, and showing distinguished visitors and the Dean of Research around his subproject. Often he discussed the past, present, and future work of his project with representatives of the five governmental departments and seven fruit-growers who had been sent to check on his progress. He was frequently invited to give progress

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reports in person at the central offices of these twelve sponsors. Each week he wrote out a full progress report which was duplicated and sent by special messenger to 3388 other projects sponsored by His Majesty's Government throughout the British Isles.

One of these remarkable documents, in an excellent state of preservation, can be found in the Museum of the Horticultural Society of Western Wales, in the village of Merthyr Tydfil. In typically logical style, the report, bound in a dark red stiff cover bearing the project number, HM2wr3801-g-(293), stamped in gold leaf, opens with a succinct table of contents:

1. Administration
2. Conferences
3. Correspondence
4. Supplies
5. Results of research

The last section, "Results of research," may have been lost during the intervening years, or it may not have been specifically required under the terms of His Majesty's contracts of that era. At any rate it is not there. But the other sections remain to gladden the hearts of those permitted to read them. Is it too much to hope that this report can be published and distributed among our young scientists in America? Such a precept should accomplish miracles for the morale and spirit of our neo-geniuses.

One day in 1685 Newton's precise schedule was interrupted through no fault of his own. He had set aside a Tuesday afternoon to receive a committee of vice-presidents of the fruit-growing syndicate when, much to his horror and Britain's deep sorrow, the news spread that the whole committee had been destroyed in a three-stage-coach smashup. As once before, Newton found himself with a hiatus. He took a leisurely walk through the luscious vineyards of the Subproject on Grapes, but not, of course, until he had obtained security clearance at the gate. While on this walk there came to him, he knew not how ("Ye thought just burst upon me," he later wrote), a new and revolutionary mathematical approach which, in less time than it takes to tell about it, could be used to solve the problem of attraction in the neighborhood of a large sphere. Newton realized that the solution to this problem provided one of the most exacting tests of his hypothesis; and furthermore, he knew, without need of pen and paper to demonstrate the fact to himself, that the solution fully supported his hypothesis. We can well imagine his elation at this brilliant discovery; but we must not overlook his essential humility, which led him forthwith to kneel and offer thanks to the King for having made the discovery possible.

On his return from this walk, Newton stopped a moment to browse in a bookstore, where he accidentally knocked a book to the floor. With apologies to the proprietor, who seemed in a mood to toss him out upon his ear, Newton retrieved the book and dusted it off. It was Norwood's *Sea-Mans Practice,* dated 1636. Opening the book at random, Newton found it contained the exact information on the length of a latitude degree that he required for the complete test of his hypothesis. Almost instantaneously, one part of his brain performed several lightning calculations and presented the result for the other part to examine; and there it was: the proof complete and irrefutable. Newton glanced at the hourglass in the shopkeeper's window and with a start remembered that he was due back at the dungeon to sign the milkmaids' time slips as they checked out for the day. He hurried out of the bookshop with the book under his arm, forgetting in his zeal that he had not paid for it.

Thus it was that His Majesty's Government supported and encouraged Newton during the trying years in which he was putting his hypothesis to the test. Let us not dally with the story of Newton's efforts to publish his proof, the misunderstanding with the editor of the *Horticultural Journal,* the rejections by the editors of *The Backyard Astronomer* and *Physics for the House-*

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wife. Suffice it to say that Newton founded his own journal in order to make sure that his proof would be published without invalidating alterations. Regrettably, he named his journal *Star and Planet,* with the result that he was branded a subversive, since Star could mean Red Star and Planet could mean Plan-It. Newton's subsequent testimony before the Subcommittee for Suppression of Non-British Ideas remains as a convincing demonstration of the great qualities that combined to make him a genius. Eventually he was exonerated, and after enjoying many years of the fame that was due him, reigning one day each year as King of the Apple Festival, Newton died happily.

THE ENTROPY CONCEPT AND PSYCHIC FUNCTION

By MORTIMER OSTOW

New York City

In his article, "Life, Thermodynamics, and Cybernetics" [1], Dr. L. Brillouin offers an objection to the conception that the recording of information involves a change in entropy as now defined thermodynamically. Such an entropy change would have to take into account whether or not the information was previously known to the observer, whether the observer can understand, and whether he is interested in, the observation. Dr. Brillouin suggests an analogy with the computation of the entropy of light beams which depends upon the absorption spectrum of the recording instrument. A new definition of entropy, he suggests, involving the nature of the receiving instrument, is therefore required for use in biology.

Dr. Richard C. Raymond, in his reply, "Communication, Entropy, and Life" [2] proposes that the entropy of a system be computed as the sum of the entropy of all its components plus a negative term representing the organization of its components. In an open system comprising a reading lamp, recorded information, and the reader, negative entropy may appear within the reader if he is interested in and can understand the information. Dr. Raymond does not state, however, at what point in the open system the entropy increases when it decreases within the reader.

In a second article, "Thermodynamics and Information Theory" [3], Dr. Brillouin concerns himself with the paradox that the amount of information can be multiplied indefinitely by such processes as printing or photography without really any loss of negative entropy from the original source. That is, it seems that negative entropy can be created indefinitely. To resolve this paradox, he suggests that information be classified in terms of absolute information and distributed information. The absolute information refers to information that exists anywhere in the universe and communication of such information does not contradict the second law. Distributed information, he says, cannot follow this law. However, we are concerned most with distributed information. The fact that one scientist in one laboratory in one corner of the world has arrived at a certain conclusion is of no help to anyone else unless his conclusions are communicated and tested. Most of our thoughts are not original, even with ourselves. If only absolute new information is found to obey the second law, then really the entropy concept cannot be used in much of our work in psychology, sociology, and communications. Brillouin also speaks of "the decay of information value" and states that this corresponds to the second law. However, he fails to demonstrate any connection between the "value" of a piece of information and its negative entropy.

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