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THE DEVELOPMENT OF THE HARVEIAN CIRCULATION[1]

AN ADDRESS DELIVERED BEFORE THE HARVEY SOCIETY OF NEW YORK ON THE OCCASION OF THE TERCENTENARY OF THE PUBLICATION OF "EXERCITATIO ANATOMICA DE MOTU CORDIS ET SANGUINIS IN ANIMALIBUS" BY WILLIAM HARVEY IN 1628

DR. ALFRED E. COHN

Member of The Rockefeller Institute for Medical Research, New York City

YOUR request, Mr. President, that I deliver this address commemorating the tercentenary of the publication of William Harvey's "Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus" gave me the liveliest pleasure and afforded me a welcome opportunity. I come to you fresh from the study of a genuinely towering intellect, inspired by the life of a great physician, full of admiration for the nature of his investigations and of the manner of his thought. I am to speak of William Harvey an ornament to mankind.

A review of Harvey's life leaves the impression that here was a man unusually favored by fortune, one who utilized with great intelligence the rare opportunities which the contemporary world afforded. For William Harvey in view of the discovery he was to make was singularly fortunate in the century and in precisely the period of that century, in which he was born; he was fortunate in his family and in the support and strength which they brought to his aid; his college was chosen for him with extraordinary prescience; he came to Padua just at the right moment; on his return to England he became associated with and was soon elected a Fellow of the Royal College of Physicians of London; he was chosen physician to St. Bartholomew's Hospital within seven years after attaining his degree; the coveted Lumleian lectureship in anatomy at the College became his in 1615 at the age

[1] Lecture delivered May 11, 1928.

of thirty-seven and afforded him in the next year the opportunity of teaching for the first time that the blood in the body of animals circulates. He was fortunate finally in his friends, many of whom were devoted to his person; in the fame which came to him in full measure; in the great length of his life of eighty years spent in the complete enjoyment of intellectual vigor.

He was a man of rather low stature, olive complexion, of moderate portliness, if one may judge from the numerous portraits still extant, dark of hair and piercing dark of eye, quick, perhaps abrupt in his gestures, moved easily to anger—but direct, imperious, jealous of the prerogatives of his calling, as witness his St. Bartholomew's reforms, but kindly withal as his friendships with Nardi, Ent, Scarborough and Thomas Hobbes amply show.

It is less on his life though than on his thought that I wish to dwell. And because there seems to be direction in his course, beginning with his entrance at Gonville and Caius College in Cambridge in 1593 when he was but fifteen years of age we do well to begin at this point. In all probability, the atmosphere of no other college could have directed his attention as may this one have done to anatomical studies. The second founder and Master, John Caius was himself a physician—most exceptional when heads were usually churchmen. He secured for his college—and for Harvey—two things of importance; an interest in anatomy and a contact with Padua where he had been student and professor. Caius returned to England in about 1544. Two years later he was giving anatomical lectures and demonstrations at the hall of the barber surgeons—the first to be given in England—in which he revealed to this fraternity "the hidden jewels and precious treasures of Cl. Galenus, showing himself to be the second Linacer." He did moreover obtain for his college of Gonville and Caius "the grant of a charter by which the Master and Fellows were allowed to take annually the bodies of two criminals condemned to death and executed in Cambridge or its Castle free of all charges to be used for the purpose of dissection, with a view to the increase of the knowledge of medicine and to benefit the health of her Majesties lieges." Unfortunately it is not known certainly whether this privilege was used or whether Harvey was

exposed to that influence of which this charter was an expression. Caius, like Linacre before and many other Englishmen after him had been attracted to the anatomical lectures at Padua, where he spent somewhat more than five years. He formed a close acquaintance with Vesalius and was indeed his fellow lodger for eight months in the Casa degli Valli just at the time when Vesalius was busy writing his "De Fabrica Humani Corporis." Later, in 1543 he began a journey through the great cities of Italy in the attempt to obtain in their libraries complete and correct versions of Hippocrates and Galen. Venn tells us that of the nine volumes of manuscripts in the library of Caius College given by the Master, the majority consist of treatises written by them. Himself a Paduan, an anatomist, a disciple of Galen and Hippocrates, a student of Vesalius—trained in the great Paduan tradition—this was the Master of Harvey's College. It is now known on the authority of Sir Thomas Barlow and of Venn, that Harvey was enrolled a minor pensioner on a scholarship. This particular scholarship was granted at the Grammar School at Canterbury—Harvey's school—to students who were intending to study anatomy and medicine and had been established on the advice of Caius. The choice of college therefore, if deliberate was wise, if accidental, fortunate. Caius had been dead (1573) five years when Harvey was born (1578) and twenty when he came to Cambridge (1593).

In 1598, or as Barlow thinks in 1600, with this background Harvey at twenty entered Padua. Here he lived for four or more probably for two years. Padua must then have been in veritable ferment. Within the century the leaders at Padua, as Sir George Newman reminds us, were an anatomist, a practitioner, a professor and a physicist—Vesalius, Fracastorius, Fabricius, Galilei. Galilei had been there since 1592. The aula magna where he taught adjoined the anatomical theatre. "In 1593, after Fabricius had been professor for thirty years, the Venetian authorities erected for him a small circular theatre which still exists, and here Harvey learned at his feet."

Of Harvey's life in Padua all too little is known. He was a member of the more select Universitas juristarum and he must

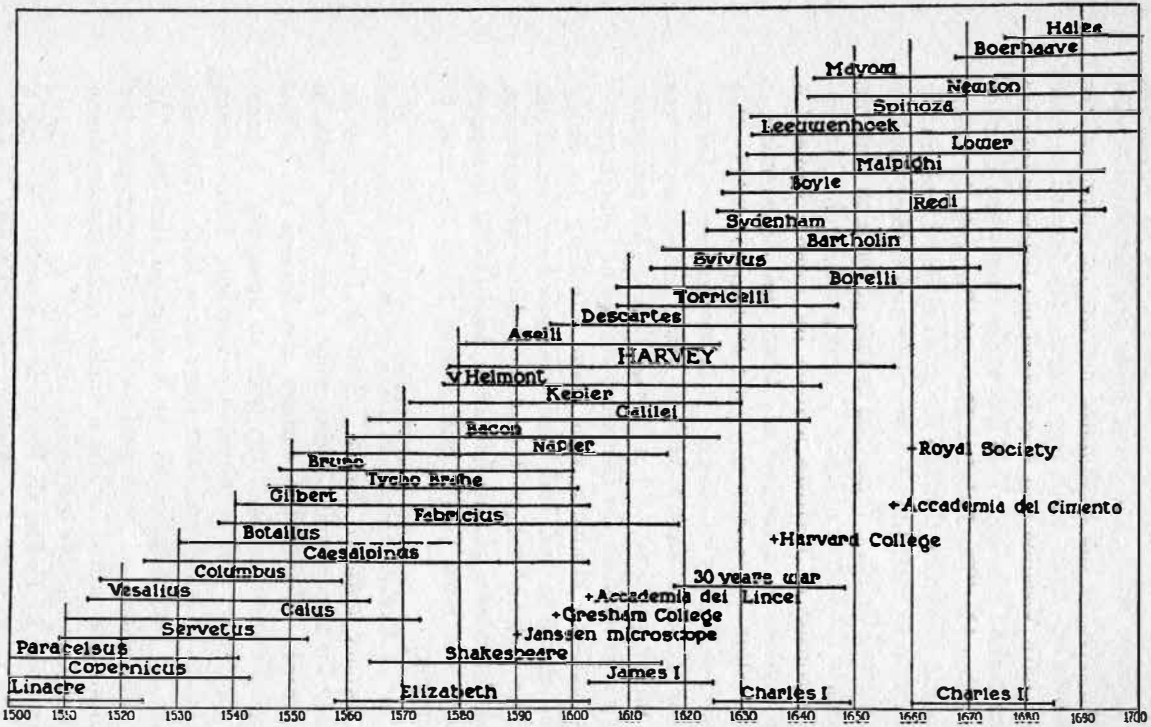

FIG. 1. In this chart the attempt is made to bring into prominence the relation in time of Harvey to his contemporaries in science, to certain political occurrences, and to important academic events. Among his contemporaries should be noticed especially Fabricius, Bacon, Galilei, Descartes, Borelli, Sydenham, Malpighi. Shakespeare died just as Harvey began his public scientific career. The Thirty Years War was fought within his lifetime. During his life also were founded Gresham College, The Accademia dei Lincei and Harvard College. The Royal Society came into existence three years after his death.

have attained some prominence for he was elected conciliarius of the English nation. His teachers were Fabricius ab Aquapendente in Anatomy, Minadous in Medicine, and Casserius in Surgery. He is believed to have been on terms of friendship with Fabricius for whom throughout his life, as his two treatises show he entertained sentiments of admiration and affection. After the negative one by Vesalius it was Fabricius who made the one significant contribution to the knowledge of the anatomy of the organs of the circulation since Galen, fourteen centuries before. The valves of the veins had been known to Sylvius but his description of them had been forgotten and they were rediscovered by Fabricius in 1574. Harvey may have learned about them directly from the Master but Fabricius's book "De Venarum Ostiolis" was not published until 1603, the year after Harvey returned to England. Great seminal years these must have been for the interests then aroused are reflected in the two treatises of Harvey that have come down to us. For besides the book on the veins, Fabricius wrote one also called "De formatione ovi et pulli" (1600).

Fabricius was followed in Padua by Casserius and Spigelius, but the great tradition was drawing to an end. With Harvey it passed to England, with Bauhin to Basel, with Bartholin to Copenhagen, with Malpighi to Bologna.

As at Cambridge so in Padua the attempt is baffling to reconstruct the influences which were exerted on Harvey. There were Fabricius and Galilei; there was the tolerant religious spirit of the Venetian republic, free to Protestant as well as to Catholic Europe; there was the tradition of doubt, the spirit of intellectual freedom; there was indeed the absorbing interest in the entire scientific Renaissance; but what would one not give for reports of the very lectures, the intimate conversations and the spirited discussions—without doubt not always pacific, which kept the town in a ferment of philosophical speculation. This is the knowledge that would give us real insight into what Harvey had stored in his mind as he turned toward England in 1602. Unfortunately all is veiled in mystery. Galilei influenced him no doubt—see the use for instance that he made of arithmetic in calculating

the volume output of the heart—perhaps the most striking argument employed in his proof that the blood circulates.

Between 1602, the year of his return to England and 1616 when he began to deliver the Lumleian lectures at the Royal College of Physicians the facts of his life are known but the detail is scant. He became Doctor of Medicine at Cambridge (1602) and years later at Oxford; he married, he was appointed (1609) physician to St. Bartholomew's hospital, he became Fellow (1607) of the Royal College of Physicians of London. But what his thought was, with whom he associated, what experiments he performed—all is obscure.

The obscurity ceases in the year 1616, the year of greatest importance in tracing the development of Harvey's thought. He was now thirty-eight years old. He had been appointed fourth Lumleian lecturer the year before (August 4, 1615) according to custom, for life. Originally the lecturer was enjoined to lecture twice a week through the year, to wit Wednesdays and Fridays, at ten of the clock until eleven. He was to read for three-quarters of an hour in Latin and the other quarter in English "wherein that shall be plainly declared for those that understand not Latin." It was his office to lecture upon the entire subject of anatomy and surgery which, for the purpose, was divided and delivered part by part, over a period of six years. Harvey was now to deliver his first course. The function was surrounded by an elaborate ceremonial. A company of great distinction was present. Although they may not have numbered above forty in all from the college, many of the curious of the town like Evelyn, Digby, Browne and Pepys may have been present. The lectures were delivered in the college, which two years before had been removed from Linacre's own house in Knightrider Street, to Amen Corner at the end of Paternoster Row. It is not altogether clear whether Harvey accurately followed the traditional order, but it is certain that this first course of the visceral lectures was delivered on Tuesday, Wednesday and Thursday, April 16, 17 and 18, 1616. A week this was of poignant interest to all those interested in the march of great events in the English speaking world, for on the Tuesday next following, April 23rd, the life of William Shakes-

peare ended at Stratford-on-Avon and there two days later he was laid to his final rest in the chancel of the parish church.

It is important to dwell with emphasis on the Lumleian lectureship, and on his lecture notes "Prelectiones Anatomiae Universalis" for they mark the date of Harvey's great departure from tradition. They contain complete evidence that what subsequently came to be recognized as the Harveian circulation was already clearly defined in Harvey's mind. He delayed the publication of the results of his observation for twelve years but in the letter of dedication to Doctor Argent, President of the Royal College of Physicians and to his colleagues which accompanied the Exercitatio of 1628 he recalls what they must have known very well: "I have already and repeatedly presented you, my learned friends, with my new views of the motion and function of the heart, in my anatomical lectures; but having now for nine years and more confirmed these views by multiplied demonstrations in your presence, illustrated them by arguments, and freed them from the objections of the most learned and skilful anatomists, I at length yield to the requests, I might say the entreaties, of many, and here present them for general consideration in this treatise." His book was apparently far from being a new story.

What Harvey's views actually were and how he sought to demonstrate their correctness I mean to analyze later in detail. But in order to understand them, it is necessary to understand the foundation on which he built. For Harvey was not only an original investigator, but was over and above this a profound and learned scholar. He knew all the anatomists and the great writers of the classical world. He knew Hippocrates, Aristotle whom he mentioned as many as fifty times in the notes alone, and Galen. He knew them all; indeed he knew them well. They do in fact ill serve his reputation who undervalue them—their acumen and intelligence, the careful and logical consideration which they, the great thinkers from Aristotle to Fabricius had devoted to solving the problems of the blood and its motion. For it was these men to whom ultimately he rose superior. The study had in point of fact gone forward in relatively few stages. Aristotle built in

large measure on his predecessors and was soon followed by the very acute anatomists at Alexandria, especially by Erasistratus. After them no considerable change was introduced until the close study which Galen gave to this problem. And after him the names of three men only need be mentioned to complete the record of significant contributions before the time of Harvey; they are Vesalius, Realdus Columbus and Fabricius.

The ancients in this connection were challenged by three great riddles; the source of animal heat, the meaning of respiration, the function of the blood.

The blood was known to be of two kinds—arterial and venous, different in color and contained respectively in the arteries and veins. Pulsation resulted from a force innate in the blood. All the arteries pulsated in unison and synchronously with the heart. The two bloods moved slowly to and fro each in its channel. It must be clearly understood that slow motion was required to permit time for the exchange of substances between each blood and the tissues. To the ancients the idea that this might be accomplished rapidly was inconceivable—and remained so even in the arguments which Riolanus the younger made against Harvey.

The function of the *venous* blood was to collect nutritive material from the intestines and to transport this by the portal vessels for further elaboration by the liver into *natural* spirits. Its onward course is a matter of first importance. On leaving the liver this blood, the venous blood, *the* blood according to Galen, divided passing downward and upward. A small amount only, and this also is important, was diverted to what is now known as the right auricle but was then regarded merely as a dilatation of the caval system. It passed next through the tricuspid valve and onward to the lungs through the pulmonary artery. The smallness of the amount which reached the right ventricle and the lungs is a major conception which permitted the maintenance of the ancient system and remained to dog the reforms of Servetus, Columbus and Caesalpinus.

The *arterial* blood also moved in a slow tidal fashion. It conveyed two things: first the pneuma, a subtle constituent of the

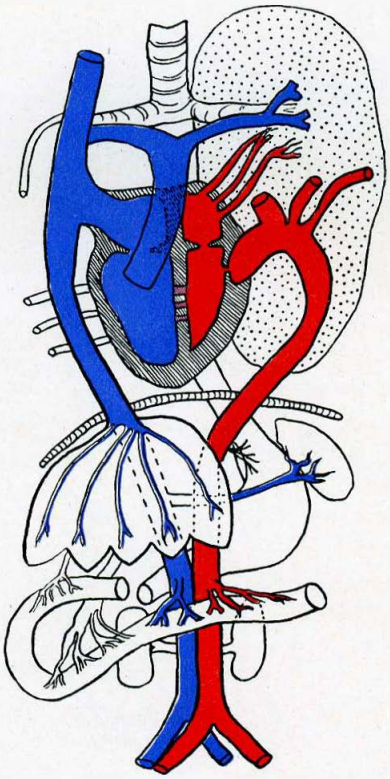

FIG. 2. The blood flow according to Aristotle. It is necessary to understand that this diagram and the next one may not be taken literally. For this neither the interpretations of the original texts nor the original descriptions themselves present a sufficient degree of accuracy. In this diagram are chiefly to be noticed: the fact that *all* venous blood enters the right ventricle; that there is no provision for interchange of substance between arteries and veins; that there is no mention of a special cerebral blood supply; that the communication between right and left ventricles differs from Galen's later invention of the pores in that there is some reason to think Aristotle regarded the septum as spongy and itself in the nature of a ventricle.

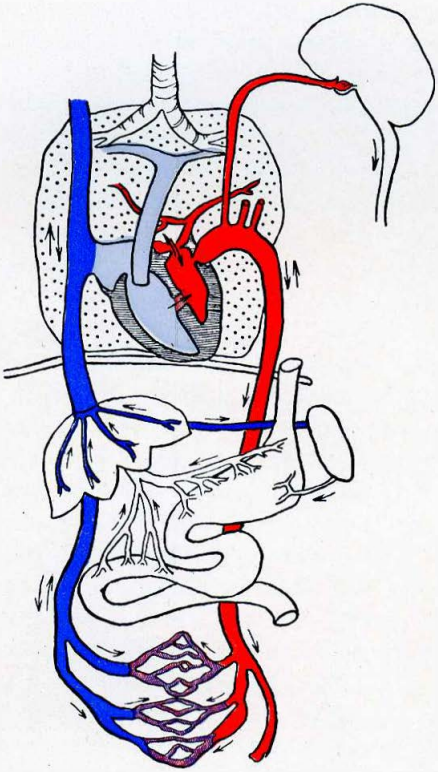

FIG. 3. The blood flow according to Galen. The changes which were introduced by Galen in his scheme of the blood flow comprise (1) anastomoses between arteries and veins, the motion of the blood in which was believed to be tide-like; (2) a supply of blood to the brain for the elaboration of vital into animal (psychic) spirits; (3) the entrance of part only of the blood into the right ventricle (as indicated by the lighter blue) so that in consequence, the liver instead of the heart was the source of the blood and the center of its flow; (4) pores in the septum between right and left ventricles were assumed to exist. This was the system which was universally accepted as correct until the demonstration of the Harveian circulation in 1616. (Modified from DE FEYFER, F.M.G.: Med. Rev., Harlem, 1907–1911.)

air, which was for the function of life an essential element. The pneuma entered the blood in the lungs whence it was carried by the pulmonary veins to the left ventricle, there further to be elaborated into *vital* spirits. The second was heat which was stored in and elaborated by the heart itself. These two qualities, vital spirits and heat were conveyed thence to the tissues. That portion of the arterial blood which went to the brain was further elaborated there into animal spirits or better perhaps called psychic spirits. So refined this substance passed along the nerves, ultimately to find its way back into the main stream by the veins. This is a Galenic account. But they were already old functions at the time of Galen who according to Allbutt conceived them much less clearly than had the Ionian Greeks (Allbutt, p. 219). Heracleitus' animating fire was "something between air and flame, penetrating and vitalizing everything," something subtler than animating fire. Straton a later member of the school of Aristotle "held that the spirit was carried in by the semen." And so says Allbutt, "the idea of combustion was lost."

It must distinctly be understood that the heart conveyed no propelling motion to the two bloods. It was clear that it was subject to motion, but the motion was bellows-like, a motion of sucking in, what would now be called a motion of active diastole. It was not the function of this motion to propel blood to the periphery, but to draw blood into its cavities, to churn and to agitate it as might be done in a mixing chamber. How little motion was conceived to be conveyed to the blood, its heat and spirits, and how little desirable this motion was regarded to be is gained from the opinion of Dr. Thomas Winston (1575–1655) professor of physic at Gresham College who feared these, i.e., blood, heat and spirits, might "be broken with continuall motion."

The motion of the blood was, as has been said, slow and tide-like. Actually small quantities only moved—drops or the fractions of drops as Riolanus supposed. In one's waking hours it moved out toward the periphery and back again to the heart during sleep. This motion was actually retained by Caesalpinus, he whom the Italians credit with the discovery of what is now called the circulation.

The double vascular system which has been described gave rise to two divergent views—those respectively of Aristotle and of Galen. In Aristotle's scheme the heart was the centre of the physiological mechanism; here arteries and veins both took their origin and to the heart both bloods were returned, once a day as Empedocles taught—each to its appropriate side. The parallel system resulted from the bilateral formation of the body. There were no anastomoses; there was as yet no great elaboration of the system of the spirits. To Galen, this arrangement seemed impossible; it permitted entrance from, though there could be no return of blood to the venae cavae once it became trapped by the tricuspid valve. The small quantity of blood which passed through this orifice and on into the pulmonary artery could be accounted for—it served a purpose. But the major portion was believed not to enter the heart. Galen regarded the liver as the centre and source of the vascular system and the originator of the blood. He took into consideration, furthermore, that the portal system led to the liver, so that three rather than two vascular systems met here—obviously a more important resort than the heart. These divergent views were still living issues in the first quarter of the seventeenth century; physicians were divided into two camps ranged one with Aristotle, the other with Galen. It was the famous conflict between the philosophers and the physicians in which the philosophers, gallantly lead by Harvey finally won. This controversy gives meaning to Harvey's statement in his letter to Slegel: "It was proper that the dean of the College of Paris should keep the medicine of Galen in repair; and should admit no novelties into his school without the utmost winnowing." Riolanus was dean in Paris—and Paris was for the camp of Galen.

So far the two bloods, arterial and venous have been described as being quite different and having no method of intercommunication. In point of fact, each was thought to exhibit in slight degree characteristic properties of the other, as if we should say both contained appropriate concentrations of oxygen and carbon dioxide. Communications were in fact believed to exist, at the periphery, in the heart, and in the lungs. Erasistratus because the arteries were empty after death, regarded them as containing

only spirits during life. But he noticed that when an artery was punctured it bled; he wisely concluded that somehow, blood passed from the veins wherein it was contained to the arteries from which it flowed and therefore he invented anastomoses—structures which remained respectable parts of anatomy until Harvey dealt away with them. These anastomoses must not be confused with those of a later time, for in them blood flowed in two directions—like a tide. That the arteries actually contained blood was demonstrated by Galen in many experiments. In his most famous one he trapped blood between two ligatures; on being incised it was obvious that the artery contained blood. Through the septum of the heart also, blood passed by small invisible and tortuous pores to be elaborated in the left ventricle into vital spirits. The septal passage also was Galen's suggestion. Finally an interchange of blood in the lungs was regarded as necessary for blood certainly passed from the venae cavae into the right ventricle and thence into the lungs where the natural passed through the first stage of elaboration into vital spirits. But since the pulmonary valves prevented its return, this blood small in amount perforce flowed onward into the pulmonary veins, squeezed into them by the collapse of the lungs. Galen's plan came perilously near that proposed by Servetus and Columbus.

To the lungs themselves, the ancients, the moderns and Harvey himself attributed four distinct functions. First they were presumed to aid in maintaining the tide of the blood by their rise and fall. In the second place, from the air, they *admitted* substances essential to life; while the blood brought to them by the pulmonary veins, *discharged* through them fuliginous vapours, excrementitious in nature. These veins provided a possible channel because the mitral valve formed of two only instead of three cusps was, so Galen believed, imperfect. The blood flowed here therefore in two directions. But the third was the most important; it was the office of the lungs to ventilate and to cool the blood, warmed sometimes to boiling by the innate heat of the heart. Aside from these three functions, the lungs protected the heart—that most important of all the organs, the very centre

of life itself. Finally the lungs shared with the heart, the coction, the elaboration of the vital spirits.

Beyond the facts of anatomy already discovered, the ancients were confronted with a number of phenomena which challenged explanation. They inferred from crude experiment that breathing was essential to life, was perhaps the source of life itself. And they knew other things. They knew for example that the heart tapped against the chest wall; they knew that the heart was muscular; they knew that the valves of the heart functioned; they knew that the arteries pulsated; they knew that arteries and veins were connected with the heart and that the arteries and veins contained blood different in color—truly a bewildering array of facts. One must read Galen to appreciate the excellence of the system he instituted, its internal coherence, its consideration of all these and other matters including the change from foetal to the post-embryonic circulation. Beside problems obviously connected with the circulation they were puzzled, as I have said, by the problem of animal heat. That heat was necessary, they surmised, for was it not a commonplace observation that when alive the body was warm, but cold when dead. A probable locus for the generation and storage of the innate heat they knew must exist. What more natural than that the heart should be selected for this purpose. Its location and vascular connections suggested its choice as the most convenient source from which to distribute heat; the heart presented the advantage moreover of close proximity to the lungs, where it could be cooled and tempered. Their choice was wise and has been justified by time.

Let them who never theorize beyond the facts criticize these ancient conclusions or regard their authors as ignorant or merely perverse. Was it not Galen who in his own life, put blood into the arteries, saw that the heart is muscular, recognized the function of the valves, though when convenient in debate, he conceived their closures to be imperfect; recognized the difficulty of tidal flow in the veins and right ventricle in the face of a competent tricuspid valve? He had moreover to see to it that spirits both natural and vital were finally conveyed to the left ventricle. And in order to perform this feat was he not obliged to invent pores

in the septum; much as Harvey later invented pores in the lungs and flesh; a supposition which Malpighi later established as a fact. Nor at the mention of his name should I fail to recall that we are this year celebrating another tercentenary, that namely of the ingenious Malpighi himself.

It is to the lasting honor of Vesalius that on the assurance of his senses, he cured the heart of this Galenic defect of the septum and by so doing set the stage for a new scene. After Vesalius a new pathway from veins to arteries had of necessity to be found. Had Galen known the valves of the veins, the one significant structure added after his time to the stock of knowledge, what use he would have made of them is an interesting speculation. Original and bold, he would surely have felt himself compelled to introduce them into his system. He might have failed in making the great discovery, but how many of the necessary data he had in hand! Galen himself has illuminating remarks to make on the conditions which govern discovery. He like so many other questioners wondered as Dalton points out, why truth is often so long obscured by the errors of the past. "One may naturally ask," he inquires "how it is that men of so much intelligence could have maintained an opinion so contrary to the truth, since they must have had some plausible reason for their belief? To which I (i.e., Galen) reply that they have left on record in their writings the grounds on which their belief was founded; and these grounds, though plausible, are not sufficient." In such matters a frequent source of error is the following. Everything which comes under the cognizance of human intelligence is comprehended either through the senses or by the reason; and as there are many things of a physical nature which escape the senses, so our reason often fails to master those of a different kind. A sincere lover of the truth, therefore, should never withhold his assent from things plainly evident on account of others which are obscure, nor accept those which are doubtful for the sake of what is really known. . . . ." A profound saying this, circumstantially repeated by Harvey himself in the introduction to his "De Generatione" forever requiring reiteration in the pursuit of a mistress so plausible as Nature.

The contribution of Vesalius has already been mentioned. So has the rediscovery of the valves of the veins. Fabricius had as a matter of fact no real use for them. He was indeed inclined to believe that they protected the veins from rupture by impeding the tendency to a rapid downward flow of blood, a service which was performed in the arteries by their heavier coats. Fabricius, great as he was, was no Galen.

But the episode of the *discovery of the pulmonary circuit* requires more detailed consideration though there is reason to believe that its significance has been somewhat exaggerated. Harvey was familiar with the account Columbus gave of it in 1559 but does not mention the earlier one, rendered much more interesting on account of its theological bias, and published by Servetus in his "Restitutio Christianismi" (1553). To Harvey it was scarcely more important than Galen's speculation, for he says in a parenthesis in his letter to Slegel: " . . . . Riolanus uses his utmost efforts to oppose the passage of the blood into the left ventricle through the lungs, and brings it all hither through the septum, and so vaunts himself on having upset the very foundations of the Harveian circulation (although I have nowhere assumed such a basis for my doctrine; for there is a circulation in many red-blooded animals that have no lungs). . . . ." (Syd., 597.)[2] Nevertheless by suggesting the pulmonary transit, contact between air and venous blood for partial purification was properly provided for. Incidentally as Professor Curtis remarks the Galenic defect of the imperfect mitral valve was cured. But neither Columbus nor Servetus did the Galenic system any real damage. In reality they strengthened it, for the systems of both continued to imply that *a small portion only* of the venous blood passed the tricuspid valve, and moved onward to the left ventricle. The valves, by the change in direction of blood flow, became competent but the erroneous system was unshaken. The main portion of the venous blood still remained in the venae cavae outside the heart and continued there its tide-like career. The *new* system was small gain indeed since by rescuing the valves from incompetence the *old* system was apparently more firmly entrenched and the chance of

[2]This refers to the works of William Harvey—see references.

discovering *the* circulation more definitely postponed. From the Galenic point of view the great gain was that the heart was still safe from the entrance of crude venous blood. Proof, indeed the very suggestion was still to be made that the *whole* blood and not merely a *small fraction* of it, traversed the lungs.

Frazer dwells with much interest on the situation brought about by the writing of Servetus and Columbus and concludes justly: "All these anatomists have been credited, at one time or another, with knowledge of the circulation, but if we turn to their accounts of the veins and liver—a very good test of their views—it is found that they were all quite innocent of any conception of the circulation. . . . . In all these cases the passage through the lungs, which had been postulated by Galen, was simply adopted to supply the left heart with the material for its manufacture of 'vital spirits,' the perforations in the septum having lost caste with most writers." Certain it is that the method, the temper, the character of the intellect displayed in the writings of Harvey are in such sharp contrast to those of his forerunners as to introduce the student of his treatise into a new world. His is no longer the vague unsatisfying recital of incompletely observed events, but the firm and tough description of a genuinely accurate observer. I omit all mention of Caesalpinus who, though interesting in himself, and no doubt entitled to some credit in the history of this matter, seems to have played no part in Harvey's discovery.

It is time to return to Harvey and to an analysis of his reasons for dissatisfaction with the inherited beliefs. There are, so far as they are known to me, three sources of information which suggest whence the hint came to Harvey that the blood actually circulates. According to Sir Norman Moore, the dawn of the idea is to be inferred from a note in his own Prelectiones in which Harvey himself attributed to Aristotle the suggestion that led to his proof. The second, I take from the Honourable Robert Boyle: "And I remember," writes Boyle "that when I asked our famous *Harvey*, in the only Discourse I had with him, (which was but a while before he dyed) What were the things that induc'd him to think of a *Circulation of the Blood?* He answer'd me, that when he took notice that the Valves of the Veins of so many several

Parts of the Body, were so Plac'd that they gave free passage to the Blood Towards the Heart, but oppos'd the passage of the Venal Blood the Contrary way: He was invited to imagine, that so Provident a Cause as Nature had not so Plac'd so many Valves without Design: and no Design seem'd more probable, than That, since the Blood could not well, because of the interposing valves, be sent by the Veins to the Limbs; it should be Sent through the Arteries, and return through the Veins, whose Valves did not oppose its course that way." The third source is Harvey himself in the Introduction to his book, where the reason assigned in his conversation with Boyle is, most curiously, omitted. He dwelt first and also longest on the error then current that the pulse and the respiration served identical ends " . . . . whether with reference to purpose or to motion, comporting themselves alike." Of this belief he disposed by showing that lungs and heart were strikingly different in structure, and that the arteries never contained air. The older authors were furthermore in contradiction with one another on all important points. Second, he found it impossible to believe that the heart, arteries and veins all beat synchronously and that the wave of the pulse passed, as Galen supposed, along the wall, rather than along the fluid column. Third, he could not conceive why different functions should be assigned to the two ventricles, the left only to elaborate vital spirits. Fourth, he could not see why, whenever it suited the argument, anatomists declared the four great cardiac valves to be permeable and especially the mitral valve which was permitted to pass fuliginous vapours but not the vital spirits. Fifth, he was overwhelmed by the variety of functions assigned to the weak walled pulmonary veins as against the stronger pulmonary artery, and was especially concerned about the to and fro motions of the blood which the systems then current postulated must take place within its walls. Sixth and finally, he saw no reason for maintaining the existence of the pores of the septum, when in the first place they could not be found and in the second, when motion through them was conceived to pass only from right to left and never in the contrary direction. To Harvey writing before the days of Stephen Hales this seemed an irrational position.

This list of objections clearly bristles with formidable difficulties. Harvey's acumen in marshalling its items raises him at once far above the level of his contemporaries. Having given sufficient reasons for embarking upon his undertaking, one the more necessary to him because "Hieronymus Fabricius of Aquapendente, although he has accurately and learnedly delineated almost every one of the several parts of animals in a special work has left the heart alone untouched," and having stated that he had almost, like Fracastorius, resigned an understanding of this organ to God, he launched out upon his great demonstration.

The argument, continued through seventeen short chapters, begins simply enough but accumulates force until at the end it becomes overwhelming. Whereas his predecessors had assigned to the blood, the sort of motion it should theoretically exhibit, Harvey proceeded differently. He studied the heart itself, not in one animal, but in animals of many species. He looked at the heart (Chap. II), he removed it from the body, he held it in his hands. He saw that its great function was to contract, that *when* doing so it became smaller, harder and paler, that *by* doing so it developed enough energy to expel blood. And then he noticed—great discovery—that the apex of the heart when in place, struck the chest—not in diastole as had been universally believed, but in systole. It followed logically that if during systole, the ventricles discharged blood, the arteries must dilate, not as a bellows to draw in blood but like a glove into which something is forced (Chap. III). So perished the notion of the simultaneous contraction of heart, arteries and veins. A more detailed examination of the motions of the heart showed (Chap. IV) that auricles and ventricles also, contracted not synchronously but in succession, four motions at two times, not four motions at four times, as Riolanus and Bauhin taught. He found evidence for this in the phenomena of the dying heart now so familiar—the ultimum moriens and the incomplete heart block of asphyxia. He proved furthermore that the auricles pumped blood into the ventricles. He saw, in the hen's egg, how "a drop of blood makes its appearance which palpitates, as Aristotle had already observed." He believed that the auricles, the last to die were also

the first to live, the *primum vivens*. To the palpitating drop of blood we shall return. He found in short that the auricles contract first (Chap. V), send blood into the ventricles, and that these contract in turn. To drive home the kind of motion which he had in mind he resorted to two illustrations; first to fire arms in which the mechanism is a chain of successive acts, trigger, flint and steel, spark, powder, flame, explosion, ball; and second to deglutition, to the passage of a morsel from the mouth through successive structures to the stomach. And in this connection he becomes a forerunner of Laennec by mentioning in passing boldly and without ornament, that "when a horse drinks . . . . the motion is accompanied by a sound . . . . ; in the same way it is with each motion of the heart, ... that a pulse takes place, can be heard within the chest." In the next sentence he came to one of his important conclusions. ". . . . the one action of the heart is the transmission of the blood and its distribution, by means of the arteries, to the very extremities of the body, so that the pulse which we feel in the arteries is nothing more than the impulse of the blood derived from the heart." This statement for its time was tremendous—not a mere revolution, but a genuine innovation.

Harvey's argument now forged forward. If what he had shown concerning the physiology of the heart was sound, why had it remained difficult, he asked, to recognize the rest of the mechanism devoted to a satisfactory blood flow. The answer was simplicity itself. It must be that the heart and lungs are crowded into such close contact, that it becomes difficult to observe what their topographical relations actually are. The pulmonary artery and the pulmonary veins are obviously short and are too soon lost in the substance of the lungs. This fact was his point of departure; he was now ready to discuss the pulmonary circuit. He described the difficulty of the ancients in searching for a passage from pulmonary artery to left ventricle. They searched for it consciously and conscientiously, just as his own countrymen searched for the North West passage. Finding none, they necessarily invented pores through the septum. But there were no pores, and there were theoretical objections anyway against their

existence. Harvey sought the pathway by other methods. He resorted to comparative anatomy and found in amphibians and reptiles, which had lungs, and in fish which had one ventricle but no lungs, what he wanted. What he found was that blood flowed from veins to arteries *through the heart;* the heart itself was the sought for corridor. And so the physiological North West passage was discovered—a quite different proof from Servetus's. For the same purpose he examined embryos, and found the same thing. Blood passed from the veins into the right ventricle, then through the foramen ovale and the ductus arteriosus directly into the aorta, obviously *not* through the lungs. He next asked if this passage exists when the lungs are absent, why does it not do so when they are present and also in use?

To show that this might be so, he relied on argument by analogy; water for example percolated through the earth, it percolated through the skin, and large quantities taken at Spas were known to pass through the parenchyma of the liver and kidneys. If passage through these was possible why might not blood percolate through the more spongy tissues of the lungs. There was another point which made this passage even more credible, for the liver being at rest exercised no propelling force on the blood, whereas the lungs, through their constant motion were capable of doing so. This was what Columbus thought, this was what Harvey also thought. But for those "who admit nothing unless upon authority," he introduced a passage from Galen which states that the blood *may* so pass and "that this is effected by the ceaseless pulsation of the heart and the motions of the lungs in breathing." (Syd., p. 42.) Harvey summarizes this and several other passages by saying: "From Galen, however, that great man, that father of physicians, it clearly appears that the blood passes through the lungs from the pulmonary artery into the minute branches of the pulmonary veins, urged to this both by the pulses of the heart and by the motions of the lungs and thorax." (Syd., p. 44.)

The proof of the pulmonary circuit rests then on evidence gathered from comparative anatomy, from dissection of the foetus and on the inference that what is true of the foetus is also true of the adult, except that the way of the blood after birth is

not direct from ventricle to ventricle, but indirect through the lungs. The left ventricle suffices "for the distribution of the blood over the body, ... the right is made for the sake of the lungs, and for the transmission of the blood through them, not for their nutrition." Both ventricles have the same, not different functions. And so perished another ancient concept. Having settled the problem of the pulmonary passage Harvey was ready to write his celebrated Eighth Chapter.

The argument had proceeded so far by simple demonstration or on the authority of Galen or of Columbus. But "when" said he "I surveyed my mass of evidence, whether derived from vivisections, and my various reflections on them" and when furthermore he analyzed the heart, its valves, and its vascular attachments and when as he says "I frequently and seriously bethought me, and long revolved in my mind, what might be the quantity of blood which was transmitted, in how short a time its passage might be effected and the like, ... I began to think whether there might not be *A motion, as it were, in a circle.*" This was the point—out at last—to which he had been leading. The heart was truly a tremendous organ "the beginning of life; the sun of the microcosm, even as the sun in his turn might well be designated the heart of the world."

Harvey had now to coordinate his several cardinal ideas; the assumption about the circular motion, the province of the heart, the difference between arteries and veins in structure and function, and to proceed to the proof. The argument now became simpler and swifter. He had just spoken of "the quantity of blood which was transmitted;" quantity was the chief consideration in his proof or the one at least which apparently attained the greatest prominence in his mind. The use of quantity was new in physiology. One cannot avoid the insistent question; Did he learn the method in Padua or was it the result of his own devices? Without doubt the method was in the air, for Borelli, who developed it one might say almost too well, was already twenty years old when Harvey published his treatise. Harvey argued as follows: If the left ventricle post mortem contains two ounces when dilated, and of course much less when contracted, and

expels from a fourth to an eighth of this, i.e. something between a drachm and a half ounce, then the total expelled in a half hour would range from ten and a half to forty-one and a half pounds. Were it the case of a sheep or dog, a scruple would be expelled, which would amount to three and a half pounds—more in both cases than the whole body contains. These, as later calculations have shown are relatively small quantities but obviously they are quantities which could not have been ingested nor could they have been drawn from the veins; there can be no escape therefore on this ground alone from the conclusion that the blood circulates. Although he believed there was usually great constancy in the volume output, this changed according to age, temperament, sleep, rest, food, exercise and affections of the mind.

It had now been adequately demonstrated that blood passed from veins to arteries by way of heart and lungs. It was necessary next to show that the circuit was completed *at the periphery* by the reverse passage, from arteries to veins. From the fact that the body could be drained of blood by dividing an artery, a fact well known to Galen and even to Erasistratus, the conclusion had been drawn that anastomoses existed.

That the blood leaves the heart by the arteries and returns to it by the veins and "that the blood passes from the arteries into the veins, and not from the veins into the arteries, and that there is either an anastomosis of the two orders of vessels, or pores in the flesh and solid parts generally that are permeable to blood" (Syd., p. 58), Harvey proved by the famous experiment with tight and middle tight ligatures about the arms. First, with *tight* ones, flow into the arms through the arteries was blocked; these became distended above, while below pulsation ceased. Flow in the veins was also blocked. There was consequently no flow in and no flow out of the extremity. Second, with a *moderately tight* one, matters were different; the arteries continued to pulsate, but the veins now were distended below. When this ligature was undone, the individual experienced a somewhat cold feeling making its way upward. Third, if a *tight ligature was loosened* and the artery palpated, "the blood will be felt to glide through" and the individual experienced a sensation of warmth.

Obviously then blood flowed into the arm through the arteries, and out through the veins. Fourth, that blood flowed from the arteries into the veins was proved by studying the case of the moderately tight ligature when pulsation of the arteries persisted, that is to say, when blood still entered but was prevented from flowing out of the arm so that the veins swelled below the ligature. All this quoth Harvey resulted from "the forcing power of the heart" and not at all from heat, pain, or vis vacui. There was surely then a passage from arteries to veins.

Harvey next employed the striking proof derived from his study of the venous valves, the one he communicated to Boyle. "Their office" said he "is by no means explained when we are told that it is to hinder the blood, by its weight, from all flowing into inferior parts; for the edges of the valves in the jugular veins hang downward, and are so contrived that they prevent the blood from rising upwards." The valves all look "invariably towards the seat of the heart." As a matter of fact he believed that "the valves are solely made and instituted lest the blood should pass from the greater into the lesser veins." He arrived at this belief from his effort to pass probes, which were uniformly blocked when directed from centre to periphery. This observation led him on to the four beautiful experiments on the superficial veins of the arm. Lay on a moderately tight ligature. Press one index finger upon a vein and with the other index finger stroke the vein upward to the next valve. You will see first that the interval becomes empty and second that it cannot be filled from above, even by stroking downward; the valve you will learn is tight. Then came the third phase; if you lift the compressing finger, blood flows into the empty vein, not from above, but you may be quite sure, from below. Finally if you repeat the first phase, that is to say, compressing and stroking upwards, one thousand times in succession and estimate the quantity of blood so allowed to pass upward, "you will find that so much blood has passed through a certain portion of the vessel; and I do now believe that you will find yourself convinced of the circulation of the blood, and of its rapid motion." (Syd., p. 67.)

Harvey must now be permitted to summarize his case. "Since

all things," said he "both argument and ocular demonstration, show that the blood passes through the lungs and heart by the action of the (auricles and) ventricles, and is sent for distribution to all parts of the body, where it makes its way into the veins and pores of the flesh, and then flows by the veins from the circumference on every side to the centre, from the lesser to the greater veins, and is by them finally discharged into the vena cava and right auricle of the heart, and this in such quantity or in such flux and reflux thither by the arteries, hither by the veins, as cannot possibly be supplied by the ingesta, and is much greater than can be required for mere purposes of nutrition; it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle, and is in a state of ceaseless motion; that this is the act or function which the heart performs by means of its pulse; and that it is the sole and only end of the motion and contraction of the heart." (Syd., p. 68.)

The formal demonstration was now complete. Harvey has brought to light the function of the heart and its dominant place in the circulation of the blood. But from his own point of view his task was not yet finished. Traditional physiology ascribed other activities to the heart to which he was obliged also to turn his attention. In tracing their origin and in appraising the meaning of them it is a great pleasure to me to acknowledge the guiding hand of my own teacher in physiology, Professor John G. Curtis, whose book "Harvey's Views on the Use of the Circulation of the Blood" prepared after his death with rare devotion and judgment by Professor Lee, is I may say, I hope without exaggeration, the most scholarly and penetrating study of Harvey's thought which has so far been undertaken.

These other functions, Harvey turned then to consider. The primacy of the heart as against the blood—of the blood as against the heart—this old Aristotle-Galen controversy Harvey could not dismiss, even from a treatise so mechanistically conceived as his "De Motu Cordis." He felt obliged to consider "Wherefore does it (that is the heart) first acquire consistency, and appear to possess life, motion, sense, before any other part of the body is perfected, as Aristotle says in his third book, De partibus Animal-

ium? And so also of the blood: Wherefore does it precede all the rest? And in what way does it possess the vital and animal principle? And show a tendency to motion, and to be impelled hither and thither, the end for which the heart appears to be made?" (Syd., p. 74.) This was one of the questions about which his views fluctuated, as many references that might be cited show, both in "De Motu Cordis" and in "De Generatione." But against Galen he takes his place definitely beside Aristotle: "Nor are we the less to agree with Aristotle in regard to the sovereignty of the heart; nor are we to inquire whether it receives sense and motion from the brain? whether blood from the liver? whether it be the origin of the veins and of the blood? and more of the same description. They who affirm these propositions against Aristotle, overlook, or do not rightly understand the principle argument, to the effect that the heart is the first part which exists, and that it contains within itself blood, life, sensation, motion, before either the brain or the liver were in being, or had appeared distinctly, or, at all events, before they could perform any function. The heart, ready furnished with its proper organs of motion, like a kind of internal creature, is of a date anterior to the body; first formed, nature willed that it should afterwards fashion, nourish, preserve, complete the entire animal, as its work and dwelling place: the heart, like the prince in a kingdom, in whose hands lie the chief and highest authority, rules over all; it is the original and foundation from which all power is derived, on which all power depends in the animal body." (Syd., p. 83.) There can be no doubt that Harvey was a confirmed Aristotelian. Did he not say in his old age " . . . . the authority of Aristotle has always such weight with me that I never think of differing from him inconsiderately." He will appear in the end, however, in "De Generatione" to have indicated his preference for the blood as the prime mover, deducing his proof from the hibernation of certain animals, and of others with blood but without a pulse. (Syd., p. 76, lines 11–29, and p. 374, lines 28–35.) The attribution of primacy to the blood is not, however, to be viewed as a capitulation to Galen. Mechanically the heart had been immovably entrenched.

Although formulated later than his treatise of 1628, Harvey's view of the cause of the heart beat is interesting and in a sense completes his account of the mechanism of the heart's motion. He says " . . . . I view the native or innate heat as the common instrument of every function, the prime cause of the pulse among the rest. This, however, I do not mean to state absolutely, but only propose it by way of thesis." (Syd., p. 138.) By swelling rhythmically at the caval entrance, the auricles and then the rest of the motion of the heart beat is set into action. It is as Curtis says: "the Harveian heart beat is caused and initiated by an Aristotelian swelling up of the hot blood." (Curtis, p. 90.) Harvey forgot a fact that he himself had adduced, namely, that fragments of muscle and the empty heart even when taken outside the body may both contract rhythmically. (Syd., p. 28.)

In discussing the pulmonary circuit of the blood it will be remembered that Harvey put the function of the respiration aside, as a subject apart from his present problem. To learn his later views his other writings must be consulted. The idea of the cooling and tempering effect of the inspired air on the innate heat when taken into the blood and the heart he inherited from Hippocrates, from Aristotle and from Galen. Aristotle had been at pains to indicate how this was accomplished. He believed that the branches of the trachea were disposed so that they lay parallel in the lungs with the pulmonary vessels and that they held this position because " . . . . no common (communicating) channel exists, for it is by contact that they receive the breath and transmit it to the heart." (Curtis, p. 15, Hist. Anim., 496a, 27–32.) This doctrine of cooling Harvey accepted at first. There was a second ancient doctrine, Galenic rather than Aristotelian which stated that the air or that part of it which entered the lungs was worked up, or concocted there first, next in the heart, and in the arteries with that air in addition which permeates the skin, and finally with a fresh supply of air in the *rete mirabile* at the base of the brain. This substance became *vital* spirits in the lungs and heart and *animal* or psychic spirits in the brain. *Natural* spirits brought from the right heart by the pulmonary artery to the lungs received there their first refinement. It was precisely

in discovering that the pulmonary circuit served this function of bringing blood to the lungs to be concocted, wherein Columbus's achievement consisted.

At first Harvey accepted both these doctrines; the doctrine of cooling and the doctrine of concoction, which we now call oxidation. The doctrine of coction he came later to deny although it had had adherents for two thousand years and was again adopted soon after his death by Lower. His denial should however be credited to Harvey as a virtue, for relying as he did on the senses, he could adduce no evidence in favor of this mechanism. He could find air neither in the pulmonary artery nor in the left ventricle even after blowing up the lungs of a dog with a bellows. The difference in color between arterial and venous blood which should have aided him he knew. It would be said now to be as good a guide to the function of oxidation as were the venous valves to the existence of the circulation. He knew the difference, indeed it had long been known, but he chose to ignore it as being slight and of no account. He came to this conclusion reluctantly because both bloods retained the same volume and assumed an identical color soon after being shed. Of the meaning and origin of spirits he came finally to have doubt. "Spirits" Harvey concluded are "not from the air." (Curtis, p. 34.) In his old age he came to deny even the cooling effects of the air. "If any one will carefully attend to these circumstances, and consider a little more closely the nature of air, he will, I think, allow that air is given neither for the 'cooling' nor the nutrition of animals; for it is an established fact, that if the foetus has once respired, it may be more quickly suffocated than if it had been entirely excluded from the air. . . . . As arguments on either side are very equally balanced, it is a question of the greatest difficulty." (Syd., p. 530.) And so the matter ended—without decision. He tried out the theories of the ancients and found them wanting. Unlike the one into which the capillaries later fitted, he recognized no new assumption concerning the respiration that he could make either in regulating the temperature or in providing a mechanism for oxidation.

Harvey's work was done. He had been inducted into the

anatomical tradition at Cambridge, he became absorbed in anatomical problems at Padua, he practised anatomical investigations in London. Throughout his life he was devoted to a problem, interest in which began in Greece, and was transferred successively to Alexandria, to Pergamon, to Paris and to Padua, in the end to come upon its final study and solution in England. It was the outstanding physiological problem of the classical world. This he inherited as all scientists inherit their problems except that in this case knowledge had already attained advanced development. He absorbed and mastered its entire literature and he unravelled completely its intricate nature. Its complexity was not less great than the problem studied by Kepler; Harvey too was required to deal with many factors, incredibly difficult to understand. To each he gave new functions, ordered them all in a simplified organism and achieved a synthesis not only unified but aesthetically satisfying.

What Harvey achieved is acknowledged by universal assent to be the foundation for further development. Whether that development necessarily sprang from what he actually accomplished is more doubtful. From the oft repeated statement that this discovery began a new era in physiology, it seems necessary to dissent. Nutrition and respiration became the outstanding subjects of investigation in the new era. The birth of psychology has been delayed until our own day. The study of the respiration remained deadlocked even though Lower eight years after Harvey's death found the clue here to the difference in the color of the two bloods. A complete solution necessarily awaited the satisfactory development and appreciation of chemistry. This way Mayow lighted, though the leaders of the Royal Society failed to see it. Then the vogue of Stahl completely obscured it. Von Helmont and Black, Priestley and Lavoisier one hundred and fifty years after the publication of "De Motu Cordis" finally discovered it and followed along Mayow's way. Lavoisier saw the way chemically at once, but it was even later that oxidation was transferred from the lungs to the tissues. Then it was that the long inquiry terminated, so checkered in its course from Aristotle and Hippocrates to Galen, from Galen to Harvey, from Harvey to Lower.

This is not the history characteristic of a discovery that initiates a new era. It is more just to regard Harvey's great achievement as the close—not the beginning of a period. He stands, not in time, but in thought midway between the ancient and the modern worlds.

No one who is in a moderate degree historically minded and interested in the evolution of the human intellect can escape reflecting on, and attempting to appraise Harvey's place in the scientific movement of the Renaissance. I find myself adhering quite naturally to a statement Mr. H. O. Taylor recently made: "We bear in mind" said he "that physical science, and each branch of it, is a unity and a whole, made of its present and its past; so that the history of any science is verily that science itself in its entirety and continuous course from its beginning to what it is now and hereafter shall come to be." No clearer example than Harvey can be furnished in evidence of this conception; he has himself amply demonstrated its truth in the course of his own writings. He summed up in its entirety the history of his science. Of his relation to his contemporaries of the seventeenth century it is more difficult to speak. The record is lamentably vague. What there is of it gives the impression of a far greater continuity with the past than of intimate sympathy with his own world. His ever present intellectual companions were Aristotle and Galen. His correspondence, so much of it as has been preserved is exasperatingly slight. In his writings there is no mention of a single contemporary English author—certainly a remarkable fact at the end of the age of Elizabeth. The single poetical quotation in "De Motu Cordis" is taken from Terence. That with men like Winston, Professor of Physic at Gresham College he had little basis for companionship is no surprise. But Gilbert was still alive when he returned from Padua and the group of inquiring intellects, Hooke, Wren, Boyle, Petty, which formed the Royal Society three years after his death had been actively gathering during the last seventeen years of his life at meetings centred around Gresham College, at the time the most interesting experiment in scientific education. With none of these men does he seem to have established relations of friendship—but rather

with Thomas Hobbes who attacked them as anti-Aristotelians. Robert Boyle that extraordinarily curious and inquiring mind, met him only once and that shortly before Harvey's death, when Boyle was already thirty years old. There was no companionship that is traceable now which can be said to have been stimulating or to have influenced significantly the course of his thought. He must have been a person singularly devoted to his special interests, little concerned with the problems of the scientific world that surrounded him. Of chemists, and of chemistry, Aubrey tells us that he held a poor opinion. And of Galilei who was making Padua alive with curiosity in subjects of really great general concern, and whose lecture room adjoined that of Fabricius so that Harvey could scarcely have escaped seeing him, we catch no echo in his writing. There is no reason to believe that what Galilei had to say had much interest for him, although many an Englishman on his grand tour must have sought him out as had John Milton. He was unsympathetic to Galilei as later to Aselli: ". . . . no kind of science can possibly flow" said Harvey "save from some preexisting knowledge of more obvious things; *and this is one main reason why our science in regard to the nature of celestial bodies, is so uncertain and conjectural.*" There is indeed an animadversion against the new astronomy in that same treatise in which he says "and there are persons who will not be content to take up with a new system, unless it explains everything, as in astronomy." (Syd., p. 123.) When in point of fact Harvey turned away from anatomy to find a metaphor for the circle in which the blood travels, he turned not to the new science but back to Aristotle and remarked: "Which motion we may be allowed to call circular, in the same way as Aristotle says that the air and the rain emulate the circular motion of the superior bodies; . . . ." (Syd., p. 46.) For mathematics, however, he developed a deep interest, especially in his declining years. He mastered Oughtred's "Clavis Mathematicae" and was working problems from it not long before he died.

There are those who profess not to rate high this achievement of Harvey. It lacks experimental elaborateness and the complicated and dazzling procedures of the modern laboratory. But if he is the great scientist who possesses a capacious mind, who sees his

problem and who sees it whole, who bends his energy to its solution and who in his demonstration exhibits that fine aesthetic quality which restrains exuberance and limits his proof to what is relevant, then I have no hesitation in linking the name of Harvey with that enviable company of which Kepler and Newton, Lamarck and Darwin are the shining examples.

I have come to the end of my analysis. It has been the record of a great history in which the intellectual giants of the race have taken their part. Neither Aristotle nor Galen needs my praise. But although not the heroes of my story, I am reluctant to part company with them without dwelling on the distinction of their contributions to the ultimate solution of this problem. The more theirs appears to be internally coherent, the greater is the credit due to Harvey who saw that what he received from them was a thing of fragments. He inherited a heart which did not work, anastomoses which did not exist, pores in the ventricular septum which would not die, vessels which knew no consistency of motion. Into the heart he breathed energy, into the vascular system order. One, certainly, of the most complex mechanisms in nature attained in his capacious intellect completely harmonious arrangement. To have brought about this innovation represents one of the great somersaults in the history of the human understanding.

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