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BRYAN MOWRY

FROM GALEN'S THEORY TO WILLIAM HARVEY'S THEORY: A CASE STUDY IN THE RATIONALITY OF SCIENTIFIC THEORY CHANGE

Introduction

THE HISTORY of science is that of older theories being challenged and eventually being superseded by newer theories. The rationality of this process of scientific theory change is a central issue in contemporary philosophy of science. This paper aims to elucidate this topic by examining an episode in the history of medical science, namely the change from Galen's theory of the movement of the heart and blood to Harvey's theory of the circulation of the blood.

In Part I the historical details include Galen's theory, the generation of Harvey's theory, Harvey's arguments for his theory, the reception of and arguments against Harvey's theory, and the fate of Galen's theory.

In Part II to elucidate the topic, the change from Galen's theory to Harvey's theory is assumed to be rational, and the ideas of Imre Lakatos and Thomas Kuhn are examined in turn to see if they can account for this rationality. It is argued that they cannot.

In Part III a different conception, which does account for the rationality of this scientific theory change, is presented. One noteworthy consequence of this conception is that it provides an argument against the context of discovery/context of justification distinction as an adequate basis for understanding the rational process of scientific theory change.

I

Galen (AD 130-200) provided an intelligible, working explanatory system for anatomy and physiology. His system made sense of the various anatomical structures then known to exist; it accounted for the processes of respiration, digestion and nourishment, and it explained the characteristic warmth and verve of the body. It is within this framework that we find Galen's theory of the movement of the heart and blood.¹

¹ For a general account see W. Pagel, *William Harvey's Biological Ideas* (Basel/New York: S. Karger AC, 1967). pp. 127-132.

Galen's Theory

1. The liver: blood formation and movement

The liver was all-important for Galen. He saw it as the origin of all veins and the organ of blood formation.² Herein, (inanimate) digested food was transformed into purplish, sluggish blood by the addition of 'Natural Spirits'. This process produced blood continuously and in small amounts. The blood then moved out through the veins to nourish all parts of the body - the impetus for its movement being the 'attractive force' of the hungry tissues. On reaching the tissues blood was consumed for nutrition - this blood being instantly, newly replaced by the liver. Only a small fraction of the blood leaving the liver found its way to the heart.

2. The heart: source of the body's heat

The heart for Galen had some similarities with skeletal muscle: its walls, for example, were composed of fibrous bundles. However, there were also marked dissimilarities: within its walls were two hollow chambers (right and left) and membranous structures called valves (these valves allowed blood flow through the heart in one direction only: their action was to shut so tightly as to prevent any reflux of blood that passed by); moreover, the heart was palpably the hottest part of the body - indeed it seemed the source of the body's heat. Thus, rather than seeing the heart as a muscle whose active movement was contraction, Galen saw it as a furnace. By virtue of its 'innate heat' this furnace actively dilated drawing blood from the liver into its right-sided chamber just as 'the-dilation of a pair of bellows sucks in air, or as the flames of a lamp suck up oil'.³ This active dilation (diastole) coincided with the active dilation of the arteries (the arterial pulse).

3. Movement of blood through the heart

Once the thick venous blood from the liver was drawn into the right heart chamber, it was at once consumed and partially transformed by the cardiac fire into a more refined, sublime type of blood - arterial blood. From here, some of this blood travelled past a valve to nourish the lungs (the lungs in turn supplying air to cool the heart); but most of this blood coursed through tiny holes in the heart's dividing septum to reach the left heart chamber. Herein, this partially transformed blood was wholly transformed by being endowed with a superlative form of life principle called 'Vital Spirits' borne by air coming from the lungs via the pulmonary veins. The waste products of this smelting process leaked back past what is now called the mitral valve into the

² See diagram 1.

³ Galen quoted in C. R. S. Harris, *The Heart and the Vascular System in Ancient Greek Medicine* (Oxford: Clarendon Press, 1973), p. 272.

pulmonary veins to be breathed out through the lungs. However, the main product, the purified, lively, scarlet-coloured blood was sucked out of the left heart chamber past another valve into the arteries, by virtue of the latter's active dilation (pulsation). This arterial blood was then distributed via the arteries to parts having special need for such pure nourishment such as the brain and the eyes, and to the body in general, giving it its characteristic warmth and verve.

4. *Galen's theory vs observation*

Galen's commitment to personal observation and experimentation led him to reject certain teachings of the Ancients. One such teaching, based on certain *post mortem* findings, was that the veins contained blood while the arteries contained only air. Various experiments convinced Galen that arteries do contain blood, but this result created a problem for his theory. Given that the liver formed the blood and distributed it through the veins, how did the blood reach the arteries? Galen postulated three routes, claiming he had seen and demonstrated each: (i) via tiny holes in the septum dividing the right and left sides of the heart; (ii) via the lungs a trickle of blood found its way from the right to the left side of the heart and into the arteries; (iii) via a body-wide network of visible anastomoses (small channels) which allowed a two-way flow of blood between veins and arteries. In this way, Galen 'fine-tuned' his theory to accommodate his findings.

Galen's Theory and Harvey's Predecessors

This was Galen's theory. It persisted substantially unchanged and unchallenged down to the Renaissance.⁴ However, from this time onwards several factors, including the rise of human dissection and the realization that Galen's theory was based on evidence gleaned from the dissection of apes and not humans, combined to bring this theory increasingly into question.⁵ Andreas Vesalius (1514 - 1564) could find no tiny pores in the heart's septum.⁶ Realdo Columbus (1516 - 1580) found the pulmonary veins to contain only blood - not air, blood and waste-products as Galen had taught. Columbus postulated that the blood moves from the right to the left sides of the heart only through the lungs and not through Galen's i-v pores. He further postulated that the active movement of the heart was systole (contraction), not diastole (dilation) as Galen had taught. Finally, the discovery of valves inside the veins⁷ by

⁴ For details see O. Temkin, *Galenism: Rise and Decline of a Medical Philosophy* (Ithaca: Cornell University Press, 1973), especially chapter IV.

⁵ For a general account see Pagel, *William Harvey's Biological Ideas*, pp. 136-204.

⁶ From here on, these tiny pores will be called 'i-v (inter-ventricular) pores'.

⁷ From here on, these will be called 'venous valves'.

Hieronymus Fabricius (1537 - 1619), William Harvey's teacher at Padua, challenged the Galenic idea of unimpeded venous blood-flow to the periphery. These ideas and investigations formed part of the corpus of traditional anatomical and physiological knowledge at the close of the Sixteenth Century.

The Generation of Harvey's Theory

1. Problems from the past

William Harvey (1578 - 1657) inherited this corpus of knowledge and found it wanting. It was, for him, 'entangled with very many and inextricable difficulties'.⁸ For example, if both the heart and the arteries dilate at the same time, how can one draw anything from the other? Again, if i-v pores exist why should not one believe that the right ventricle draws 'Vital Spirits' from the left ventricle rather than that the left, through the same pores, draws blood from the right?⁹ Further, Galen's theory was self-inconsistent: Galen had stated that the heart valves shut so tightly as to prevent any reflux of blood that passed by; he also stated that waste-products from left ventricular combustion leaked back past the mitral valve on their way to the lungs. That is, Galen seemed to say that the heart-valves were both competent and not competent. Moreover, Galen's opinions were inconsistent with those of more recent anatomists. For example, Galen stated diastole and not systole as the true movement of the heart, whereas Columbus stated the reverse. Thus, Harvey resolved to examine these matters 'in the light of anatomical dissection, personal experience many times repeated, and diligent and precise observation'.¹⁰

2. Comparative method and dying hearts

Most of all, Harvey was dissatisfied with Galen's account of the movement of the heart and its connection with the arterial pulse. He investigated by performing vivisections on mammals. However, he met with problems - the chief one being that the speed of the mammalian heart-beat made it almost impossible to distinguish dilation from contraction.¹¹ To circumvent this problem (i) he implemented the comparative method learnt from Fabricius and sanctioned by Aristotle; he examined slow-hearted, cold-blooded creatures (such as fish and reptiles); (ii) as well, he examined the dying and therefore slowly-beating hearts of mammals such as dogs and pigs. In both sets of

⁸ W. Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and Blood in Living Creatures*, G. Whitteridge (trans.) (Oxford: Blackwell Scientific Publications, 1976), p. 16.

⁹ *Ibid.*, p. 20.

¹⁰ *Ibid.*, p. 10.

¹¹ *Ibid.*, p. 29.

experiments, the heart-beat was slow enough to let Harvey see the two phases, one after the other.

‘At last using daily more diligence . . . and comparing many observations’,¹² Harvey elucidated this matter. The active movement of the heart was not diastole, but systole. The heart in diastole did not actively draw blood into its chambers but was dilated passively by the inflowing of blood; whereas in systole, the force of the contracting heart drove the blood out into the arteries thereby producing the arterial pulse; thus the pulse was not an active movement drawing blood out from the left ventricle, but rather a passive movement caused by the impulsion of blood from the contracting heart. Furthermore, the arterial pulse was synchronous with heart systole, not with heart diastole as Galen had thought.

Continuing this logical sequence of investigation, Harvey delved deeper into the nature of cardiac systole. Eventually he became convinced that ‘the wave of heart contraction passed from top to bottom not from right to left’¹³ as Galen thought; (that the heart contracted from right to left supplied, for Galen, the force necessary to propel blood through the i-v pores). This led Harvey to his next problem. Since on this and other evidence there are no i-v pores, how does the blood get from the right side of the heart to the left? Realising that the connection in man of the heart and lungs made the whole matter very difficult to sort out,¹⁴ he again turned to examine less complex creatures, those without lungs and with single-chambered hearts (such as crustaceans and reptiles). This experimental evidence, combined with (i) embryological investigations,¹⁵ (ii) detailed examination of the nature and function of heart valves, and (iii) observations that the pulmonary artery (leading into the lungs) and the aorta pulsated, while the pulmonary vein (leading from the lungs to the left heart) did not pulsate, led Harvey to conclude that (iv) ‘the action of the heart in so far as it is an instrument of movement is to send blood from the vena cava into the lungs through the pulmonary artery and from the lungs through the pulmonary vein into the aorta’.¹⁶ Thus he had established the pulmonary, but not as yet the general, circulation of the blood.¹⁷

3. *Blood quantity considered*

From (i) the above established data, (ii) considerations concerning the size and symmetry of the heart chambers and vessels leading into and out of the heart, and (iii) the consideration that such structures must have been made for

¹² *Ibid.*

¹³ *Ibid.*, p. 39.

¹⁴ *Ibid.*, p. 52.

¹⁵ *Ibid.*, pp. 58 - 60.

¹⁶ *Ibid.*, p. XXX.

¹⁷ See diagrams 2 and 3 for illustration

a purpose since 'Nature . . . makes nothing in vain',¹⁸ Harvey came to realise (iv) that the quantity of blood passing through the heart from the veins to the arteries in a unit of time was (a) far greater than that which could possibly be replenished from ingested food (cf. Galen) and (b) so great that the veins would be empty and the arteries would burst unless the blood somehow flowed from the arteries back again into the veins and returned to the right ventricle of the heart. This led Harvey to think (v) 'whether the blood might not have a kind of movement as it were in a circle'.¹⁹ Harvey had *reasoned* his way to his seminal idea of the circulation of the blood.

Placed as it was at the end of a lengthy chain of problem-solving, Harvey's idea had the status of a plausible hypothesis: it was worthy of further investigation and, if supported by observational and experimental results, Harvey could rationally move from considering it as a plausible hypothesis to accepting it as if it were true.

Harvey then set about investigating his hypothesis.

Harvey's Arguments for his Theory

He resolved his hypothesis into three propositions:

- A. That the heart's pulse transferred the blood incessantly from the vena cava into the arteries in so great a quantity that the blood could not possibly be provided by ingested food, and in such a way that the whole mass of blood passed through the heart in a short time.
- B. That the arterial pulse drives the blood continuously, consistently and incessantly into every part of the body in far greater quantity than is necessary for nutrition.
- C. That the veins themselves uninterruptedly bring back the blood from every part to the heart.²⁰

He then supported each with two different types of arguments.

1. Argument from quantity

In support of A, Harvey made a simple calculation about the amount of blood passing through the heart in a unit of time: ascertaining on the basis of *post mortem* findings the least amount of blood ejected with each heart-beat, and multiplying this by the number of heart-beats in one half-hour, Harvey arrived at a quantity of blood far greater than that contained in the whole body, let alone that which could possibly be supplied by ingested food or

¹⁸ *Ibid.*, pp. 74-75.

¹⁹ *Ibid.*, p. 75.

²⁰ *Ibid.*, p. 78.

contained in the veins. Therefore, the blood circulates. Similar calculations supported B and C.

All these calculations were sustained by:

2. *Argument from experimentation*

Proposition A was supported by several experiments. For example, Harvey severed a sheep's main artery and collected and weighed the blood ejected in a unit of time?²¹ He also examined a live snake and found that when the vena cava was compressed the heart quickly blanched and emptied, whereas when the aorta was similarly compressed the heart became swollen and purple.²² These and other experiments supported the idea that a great amount of blood passed through the heart in a short amount of time thereby posing a serious challenge to Galen's idea that the liver continually produced blood in small amounts from digested food.

Harvey supported B by experiments with ligatures. In the limbs, arteries run deep while veins course superficially. A very tight ligature around the upper arm compressed both arteries and veins. No visible change subsequently occurred in the hand or veins. A medium-tight ligature compressed the veins but not the arteries. The resultant influx of blood caused hand engorgement. Loosening a ligature from very tight to moderate tightness caused blood to rush into the limb engorging the hand and swelling the veins. These and similar experiments²³ showed that blood flows outwards from the heart, not through the veins as Galen thought, but through the arteries to the peripheral tissues wherein it 'flows from the arteries to the veins and not contrariwise' either by way of 'an anastomosis of the vessels or via porosities in the flesh'.²⁴ Further ligature experiments showed that venous valves allowed blood to flow only toward the heart, thus supporting proposition C.²⁵

The following arguments supported Harvey's hypothesis as a whole:

3. *The argument from explanation*

To explain a natural phenomenon satisfactorily one must, it was thought, consider the final cause, the purpose of that phenomenon's existence and form. A sequence of cause and effect was manifest in the very nature of things: Nature, it was held, does nothing in vain.

Harvey complied with this requirement,²⁶ arguing that the circulation of the blood was the purpose of the existence and structure of many apparently

²¹ *Ibid.*, p. 79.

²² *Ibid.*, pp. 82-83.

²³ *Ibid.*, pp. 88-95.

²⁴ *Ibid.*, p. 93.

²⁵ *Ibid.*, pp. 103-105.

²⁶ For details see (1) W. Pagel, *New Light on William Harvey* (Basel, Switzerland: S. Larger AG, 1976), pp. 14-18; (2) Pagel, *William Harvey's Biological Ideas*, p. 41.

disconnected phenomena observed during dissection and vivisection. For example, the left ventricular wall was thicker than the right because it needed a greater force to propel blood out through the aorta and into the entire body than the right ventricle needed merely to pump blood through the spongy, loosely textured lungs.²⁷ The difference in wall thickness between arteries and veins could also be explained. The arteries needed thicker walls to withstand the impulsion of blood thrust out from the left ventricle; the veins had no such need and were thus thin-walled. Moreover, arterial wall thickness decreased with increasing distance from the heart until in the extremities very small arteries had the same wall-thickness as the veins; this was because the 'shockwave' of impulsed blood lessened in force with increased distance from the heart.²⁸

Certain other findings, previously incorrectly explained, also became clear. At *post mortem* the left ventricle and arteries were often empty of blood, while the veins were full. Harvey's theory explained this: blood passes from the veins to the arteries only through the heart and lungs. The lungs die before the heart. Therefore the left ventricle continues to pump blood out of the arteries into the veins but receives no further blood through the lungs.²⁹

Moreover, various medical practices such as the varied use of ligatures in blood-letting, amputation and removal of tumours - incorrectly explained on Galen's theory - were elucidated on Harvey's theory.

Thus Harvey claimed that the circulation of the blood brought together all these disparate phenomena, explaining them in a neat, uncontrived way. 'It was', said Harvey, 'very hard for any one to explain by any other way . . . for what cause all these things were made and so appointed?'³⁰

But the circulation of the blood was *itself* a phenomenon. What was *its* purpose? Harvey gave the following reply. The blood circulates to regain its life-sustaining heat lost to the tissues: once in the cold extremities the blood coagulates and loses its life - anyone can see peoples' extremities are cold, blue and lifeless in cold weather; therefore it must return to the heart, its source, its home and hearth wherein it is revitalised and then redistributed.³¹ This and other Aristotelian arguments Harvey gives in support of his thesis. But Harvey claims these as accessory arguments only.³² It was his wish that 'above all else [his theory] be established and supplied with arguments based on anatomy'.³³ Nevertheless, they support his theory.

²⁷ Harvey, *An Anatomical Disputation*, p. 124.

²⁸ *Ibid.*, p. 130.

²⁹ *Ibid.*, p. 83.

³⁰ *Ibid.*, p. 133.

³¹ *Ibid.*, pp. 108 ff.

³² *Ibid.*, p. 108.

³³ *Ibid.*, p. 117.

Thus, the circulation of the blood not only explained many observed, apparently disconnected phenomena but was itself explained by other phenomena, namely the preservation of heat-bearing, life-giving blood. Furthermore, Harvey predicted that the circulation of the blood may plausibly explain a number of other phenomena 'enveloped in much doubt and obscurity'.³⁴ This is his argument from prediction.

4. Argument from prediction

The phenomena so baffling to Harvey and his contemporaries included: (i) the spread of 'contagion' from a poisoned wound or from the bite of a rabid dog, (ii) the spread of syphilis from its initial site;³⁵ (iii) the inward effects of medicaments such as colocynth applied externally,³⁶ and (iv) the prognostic significance of the arterial pulse.³⁷ Because there were no anatomical data from dissection or vivisection substantiating these phenomena, then it could only be predicted that circulating blood explained them. Take for example the spread of syphilis from its initial site. Here, anatomical evidence was lacking since in fact the causative micro-organism *Treponema pallidum* was yet to be discovered; however, the clinical signs of syphilis were protean and included skin rashes, swollen lymph glands, malaise, fever, headaches, muscle pains, skin ulcers and joint swelling. From these observations on patients Harvey could only forecast (predict) that the 'contagion' of syphilis is at first 'imprinted' on the genitals and then taken via the returning blood to the heart, whence it is disseminated throughout the body thus explaining the diverse clinical signs.³⁸

Because (i) Harvey considered anatomical demonstration as ultimate evidence and (ii) the argument from prediction lacked this evidence, then the argument from prediction could be only another accessory argument for his hypothesis.

On the basis of the above main arguments from quantity, experimentation and explanation (except that concerning the purpose of the blood circulation) together with the accessory arguments from prediction and from the purpose of the blood circulation, Harvey could move rationally from treating his idea as a plausible hypothesis to accepting it as if it were true.

In 1628 Harvey published his findings in *An Anatomical Disputation Concerning The Movement of the Heart and Blood In Living Creatures*.

³⁴ *Ibid.*, p. 113.

³⁵ *Ibid.*

³⁶ *Ibid.*, p. 114.

³⁷ *Ibid.*, p. 113- 114.

³⁸ *Ibid.*, p. 113.

Reception of and the Arguments against Harvey's Theory

Harvey's theory shocked the medical world. It was at first almost universally rejected. Some anatomists completely ignored it. For example, Harvey's contemporary and surgical colleague Alexander Read (1586 - 1641) must have known of Harvey's work. Yet in his *Manual of the Anatomy, or Dissection of the Body of Man* published first in 1634 and reprinted five times up to 1658, Harvey was not mentioned.³⁹ However, opposition did soon appear in print and it continued for 20 years. Let us now see what the critics' arguments were and how Harvey and his supporters dealt with them. These arguments can be examined under the following headings:

1. *Appeal to authority*

Because Harvey's theory conflicted with the traditional corpus of knowledge, it was therefore to be rejected. This argument was common early in the controversy. James Primerose (1592 - 1654) writing in 1630 denied all of Harvey's conclusions supporting his denials with quotations chiefly from Galen and Vesalius. For example, to Harvey's claim that i-v pores could not be found in dissection, Primerose replied that this was so because they close up after death but that 'when the heart beats and is contracted and dilated, then the pores in it in some manner also collapse and are dilated'.⁴⁰ In any case, these pores were seen, he asserts, by Vesalius and others. Yet, Primerose produced not one piece of experimental evidence in support of this denial. This approach failed to meet Harvey's theory on its own stated ground. Not surprisingly, the appeal to authority quickly lost favour.

2. *Argument from explanation*

An early argument was that Harvey's theory could not explain phenomena easily explained on the traditional account. For example, Descartes, in 1637, accepted that the blood circulated but rejected Harvey's explanation of cardiac motion given in terms of the heart's 'pulsific faculty'; this explanation was, for Descartes, obscurantist; he inclined to a more mechanical view of the heart as a kind of (Galenic) furnace supplying motive power to the circulation by virtue of its innate heat.⁴¹ Descartes claimed for his explanation of cardiac motion that it could explain many phenomena (such as digestion, the use of respiration, and the difference in colour of venous and arterial blood) inexplicable on Harvey's theory. Descartes' theory initially seemed plausible;

³⁹ G. Keynes, *The Life of William Harvey* (Oxford: Clarendon Press, 1966), pp. 318- 319.

⁴⁰ G. Whitteridge, *William Harvey and the Circulation of the Blood* (London: Macdonald and co., 1971), p. 151.

⁴¹ R. Descartes, *The Philosophical Works of Descartes*, Vol. I, E. S. Haldane and G. R. T. Ross (trans.) (Cambridge: Cambridge University Press, 1973), p. 113.

however, by the late 1640's Harvey and his followers [in this instance Johannes Walaeus (1604 - 1649)⁴² and Sir Kenelm Digby⁴³] had (i) effectively countered Descartes' view of cardiac motion and (ii) provided plausible explanations for those phenomena initially explained only by Descartes.

Another form of this argument concerned the purpose or final cause of the circulation. Harvey had already treated this subject, but his opponents were unconvinced. It was traditionally held that the heart purified and distributed the blood only once, whereas Harvey maintained that this same blood was subject to perpetual purification. To what purpose? Harvey replied to critic Caspar Hoffman (1572- 1648) in 1636 that he had deliberately omitted such discussion 'simply because [he had tried] to investigate the phenomenon itself without having established the wherefore'.⁴⁴

He admits that he made some suggestions about final causes but these he 'had not yet proved'.⁴⁵ The heart for Harvey, pumped the blood in a circuit - whether it also added heat, he was as yet unsure. However, by the late 1640's embryological investigations had convinced him that the blood, not the heart, was the source of the body's heat,⁴⁶ and that therefore the circulation's purpose was to distribute the blood's innate heat to the body, thus sustaining life.

By the late 1640's, then, Harvey had provided a plausible reply to this criticism concerning the purpose of the blood circulation.

3. *Argument from quantity*

Early in the dispute, the amount of blood passing through the heart in a unit of time was for opponents such as Hoffman 'a fact which cannot be investigated, a thing which is incalculable, inexplicable, unknowable'.⁴⁷ Harvey had thrown off 'the habit of an anatomist and suddenly put on that of a logistician'.⁴⁸ This reaction is understandable seeing that Harvey's argument from quantity was the first of its kind in the history of physiology.⁴⁹ However as the controversy wore on this quantitative method became increasingly accepted as a legitimate, fruitful method of inquiry, based as it was on observational and experimental findings. For example in 1641, Walaeus (i) supported Harvey's findings with a series of original experiments, observations and arguments, and (ii) substantiated his quantitative method by

⁴² See in Pagel, *New Light on William Harvey*, pp. 113 - 135, especially pp. 127- 128.

⁴³ Whitteridge, *William Harvey and the Circulation of the Blood*, p. 159.

⁴⁴ *Ibid.*, p. 165.

⁴⁵ *Ibid.*, p. 166.

⁴⁶ Harvey, in Robert Willis (trans.), *The Works of William Harvey MD*. (London: Sydenham Society, 1847), pp. 136- 137.

⁴⁷ Hoffman quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, p. 241.

⁴⁸ *Ibid.*, p. 241.

⁴⁹ Harvey, *An Anatomical Disputation*, p. 83 n.

producing a fully quantified account of gastric digestion in terms of stomach acid.⁵⁰

4. *Argument from experimentation*

Critics soon realised that Harvey's theory depended on there being a one-way transfer of blood from the ends of the arteries into the ends of the veins. But this blood flow was not visible to the naked eye; indeed the microscopic structures (capillaries) effecting this flow were not discovered until 1661 by Marcello Malpighi (1628 - 1694).⁵¹

How did Harvey deal with this empirical anomaly? He did not know precisely how this flow occurred yet he was certain that it did occur, it being a necessary event in the circulation of the blood which, for other reasons, must go on in the body.⁵² And this he argued in his book. However, by 1651⁵³ Harvey had developed a sound, independent case. He disposed of the rival Galenic postulate that a two-way blood flow occurred through visible anastomoses directly connecting arteries and veins on the following observational and experimental grounds: (i) blood flowed from veins to arteries via only the heart and not via Galenic anastomoses;⁵⁴ (ii) the smallest arteries were always found to have smaller diameters than the smallest veins - one would have expected equal diameters had they been directly linked;⁵⁵ (iii) the smallest veins did not pulsate - again one would have expected pulsation had they been anastomosed;⁵⁶ and (iv) Galenic anastomoses were nowhere to be found. The only structures in any way resembling these anastomoses were found only in three places in the body - one being the plexus of vessels at the base of the brain. Moreover, Harvey's experiments showed that at each place a one-way, not a two-way, blood flow occurred. How was such a one-way flow achieved in these places? Harvey postulated that the smaller-diametered arteries fitted into and tapered off inside the veins.⁵⁷ This allowed blood to flow only from the arteries to the veins, in the same way as what is observed to happen in the conjunction between the ureters and the bladder (and of the bile duct with the intestine). Here, the ureters course tortuously for some distance in the bladder wall thus allowing urine to flow only one way: from the ureters into the bladder.⁵⁸

⁵⁰ Pagel, *New Light on William Harvey*, pp. 115-116.

⁵¹ L. Clendening *Sourcebook of Medical History* (New York: Dover Publications, 1942), pp. 209 ff.

⁵² Whitteridge, *William Harvey and the Circulation of the Blood*, p. 168.

⁵³ See his letter to Paul Marquard Slegel in Willis, *The Works of William Harvey*, pp. 596 - 603.

⁵⁴ *Ibid.*, p. 602.

⁵⁵ *Ibid.*, p. 600.

⁵⁶ *Ibid.*, p. 602.

⁵⁷ *Ibid.*, p. 600-601.

⁵⁸ *Ibid.*, p. 601-602.

Thus Harvey developed independent argument based on experiment and observation to counter a serious empirical anomaly for his theory. Other less pressing anomalies were dealt with in similar vigorous fashion.

These were the arguments raised against Harvey's theory in the twenty years of controversy following publication. How did Galen's theory fare during this time?

Fate of Galen's Theory

Initially it was in a strong position. For example, it could explain phenomena (such as digestion and nutrition) that Harvey's theory could not. But as Harvey's innovative, fruitful techniques (quantification and ligature experiments) became increasingly accepted, and his findings were supported and augmented by other workers (such as Johannes Walaeus⁵⁹ and Paul Marquard Slegel),⁶⁰ Galen's theory found itself having to account for this mounting adverse evidence; until towards the end of the controversy, it had to compromise and try to accommodate Harvey's theory. The 1648 - 1649 Riolan - Harvey exchange illustrates this compromise and its outcome. Jean Riolan (1577 - 1657) attempted to show 'how the circulation occurs . . . without destruction of the ancient medicine.'⁶¹ He accepted that the blood circulated in major vessels like the aorta and vena cava, but not in the intestines, limbs, or outer parts of the body.⁶² Against this, Harvey (i) pointed out inconsistencies in Riolan's position: for example, arteries on Riolan's own admission pumped blood into the intestines; since this blood cannot return against the influx through the same arteries, it must continue on its way through the portal vein and back to the heart (i.e., it must circulate); for otherwise, the portal vein would burst⁶³ and (ii) performed quantitative experiments with ligatures which argued for the intestinal circulation of the blood.⁶⁴ Riolan also believed in Galenic anastomoses. We have already seen Harvey's rebuttal.⁶⁵ To Riolan's persistent belief in i-v pores, Harvey offered in addition to earlier experiments and arguments, one further experiment 'from the cogency of which there is no escape'⁶⁶ tying the pulmonary artery, vein and aorta in a hanged man, Harvey inserted a tube through the vena cava into the right ventricle, and made an opening in the left ventricular wall. He

⁵⁹ Pagel, *New Light on William Harvey*, pp. 113 - 135.

⁶⁰ Keynes, *The Life of William Harvey*, p. 332.

⁶¹ Riolan, quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, p. 182.

⁶² *Ibid.*, p. 181.

⁶³ Willis, *The Works of William Harvey*, p. 92.

⁶⁴ *Ibid.*, pp. 92 ff, p. 141.

⁶⁵ See p. 12.

⁶⁶ Harvey, quoted in Willis, *The Works of William Harvey*, p. 597.

then forced water through the tube with the result that the right ventricle and atrium swelled enormously, but not one drop of water or blood escaped into the left ventricle. To this Riolan did not reply.

Riolan also used quantitative reasoning. Assuming that the heart pumped no more than one or two drops per beat and estimating the number of drops per hour, he concluded that no more than one or two circulations occurred per day.⁶⁷ This agreed with Galen's conception of the liver continually producing a small amount of blood from digested food. Harvey provided strong experimental evidence against Riolan's basic assumption: the heart, again on Riolan's own admission, pumped the blood continually: and when the aorta was cut very near the heart blood poured out 'in jets as if it were forced from a syringe'⁶⁸ not drop by drop as Riolan held. This combination of argument and evidence seriously challenged Riolan's assumption. The challenge was not met. Thus Harvey's counter-arguments (further strengthened in 1650 by those of Slegel)⁶⁹ had charged Riolan's compromise theory with internal inconsistency and disagreement with results of experiments and observations. If it was to survive, these charges would have to be answered. However, no such answer was forthcoming from either Riolan or other Galenists. In contrast, Harvey's theory had replied vigorously to all major criticisms thereby presenting itself as an alternative worthy of acceptance.

By 1651 Harvey's theory was generally accepted. It was being taught by professors in medical schools all over Europe.⁷⁰ Harvey died in 1657 being one of the very few, Hobbes tells us, who 'had established a new doctrine in his own lifetime'.⁷¹

II

We come now to the key issue: to elucidate the notion of rationality of scientific theory change. This issue is approached in the following manner: (i) assuming the change from Galen's theory to Harvey's theory was rational, (ii) we examine the ideas of Imre Lakatos and Thomas Kuhn to see if they can account for this rationality and, concluding that they cannot, (iii) we present an alternative conception of the rationality of scientific theory change which can explain the rationality of the change from Galen's theory to Harvey's theory.

⁶⁷ Whitteridge, *William Harvey and the Circulation of the Blood*, pp. 180-181.

⁶⁸ Harvey, quoted in Willis, *The Works of William Harvey*, p. 120.

⁶⁹ See Harvey's letter to Paul Marquard Slegel in Willis, *The Works of William Harvey*, pp. 596-601.

⁷⁰ E. Neil, *William Harvey and the Circulation of the Blood* (London: Priory Press, 1975), p. 74.

⁷¹ T. Hobbes quoted in Keynes, *The Life of William Harvey*, p. 389.

Lakatos' Conception of the Rationality of Theory Change

1. What constitutes a 'research programme'

According to Lakatos, how a new theory is generated and comes to compete with its older rival is irrelevant for the understanding of the rationality of theory change.⁷² Having no plan of research, no guiding 'heuristic', the generation of a new theory is merely 'a long, preliminary process of trial and error.'⁷³

Thus Harvey's theory would come up for consideration only after its publication in 1628 - only after it had become a fully-articulated 'research programme',⁷⁴ whose 'hard core' included the view that the quantity of blood pumped by the heart in a short time was far greater than the liver could produce from digested food. Protecting this core from refutation were 'auxiliary assumptions' such as the view that even though blood cannot be seen to flow from 'the minutest arteries into the finest veins',⁷⁵ it does not follow that this flow does not occur.

Guiding Harveian research was the 'positive heuristic' which included the idea that the quantitative method could fruitfully be applied to the investigation of anatomical and physiological phenomena.

What then, would Lakatos want to say about the rationality of Harvey's fully-articulated theory (research programme) superseding Galen's?

2. Lakatos' criterion of rationality

According to him, a theory should be accepted over its rival if and only if it is progressing; that is, if and only if it predicts novel facts which have been corroborated.⁷⁶ Acceptance on this ground is for Lakatos the only 'good objective reason'⁷⁷ for scientific theory change. But before we can apply this criterion of rationality to Harvey's theory we must be clear what Lakatos means by a 'novel fact'. Lakatos came to adhere to Elie Zahar's notion of novel fact,⁷⁸ namely, 'a fact will be considered novel with respect to a given hypothesis if it did not belong to the problem-situation which governed the

⁷² I. Lakatos, 'History of Science and Its Rational Reconstructions', in Boston *Studies in the Philosophy of Science*, Vol. VIII, R. C. Buck and R. S. Cohen (eds.) (Dordrecht, Holland: D. Reidel, 1971), pp. 92, 105-106.

⁷³ I. Lakatos, 'Falsification and the Methodology of Scientific Research Programmes', in *Criticism and the Growth of Knowledge*, I. Lakatos and A. Musgrave (eds.) (Cambridge University Press, 1970), p. 133 n.

⁷⁴ *Ibid.*, pp. 132-138.

⁷⁵ Harvey, quoted in Willis, *The Works of William Harvey*, p. 599.

⁷⁶ Lakatos, *Criticism and the Growth of Knowledge*, pp. 116, 118.

⁷⁷ See *Ibid.*, p. 155 and I. Lakatos and E. Zahar 'Why did Copernicus' Research Program Supersede Ptolemy's?' in *The Copernican Achievement*, University of California Press, 1975), p. 380. R. Westman (ed.) (California:

⁷⁸ *Ibid.*, p. 376.

construction of the hypothesis'.⁷⁹ Implicitly, this notion gives us two types of novel facts: (i) those known before the hypothesis which were not part of the problem-situation, and (ii) those known only after the hypothesis which, therefore, could not have been part of the problem-situation.

3. Lakatos' criterion of rationality applied to Harvey's theory

Having elucidated Lakatos' notion of 'novel fact' and remembering that such facts must be corroborated, we can now apply Lakatos' criterion of rationality of Harvey's theory. Thus we must ask: Did Harvey's theory predict any such novel facts which had been corroborated by the time it was accepted? We will examine types (i) and (ii) separately.

The answer for type (i) is no. Let us recall that even facts such as the great quantity of blood transmitted by the heart belonged to the problem-situation governing the construction of Harvey's hypothesis:⁸⁰ this fact about blood quantity had its context in Galen's idea that the liver produced blood in small amounts from digested food; further, it was a fact necessary for the construction of Harvey's hypothesis that the blood circulated. The nature and timing of heart systole and diastole was also part of the problem-situation: that the blood circulated could not have been formulated without it. Other facts similarly located were the non-existence of i-v pores, the circulation of blood through the lungs, the nature and function of the heart valves, and the centripetal direction of blood flow in the veins.

So now we ask: Did Harvey's theory predict any type (ii) novel facts corroborated before its acceptance? The answer is again no. In fact, some of these, such as how intestinal chyle (emulsified fat) was produced and distributed, were refuted. The rest were certainly corroborated, but not until after Harvey's theory was generally accepted. Recall, first, the facts claimed by Harvey himself as predictions.⁸¹ Remember, for example, Harvey's prediction that infection (from poisoned wounds, rabid dogs, and from the initial symptoms of syphilis) spread throughout the body via the blood circulation. Moreover, the predictions that bacterial infections,⁸² rabies,⁸³ malaria⁸⁴ and syphilis⁸⁵ were spread via the circulation were not corroborated until the Nineteenth Century. Second, there were novel facts other than those Harvey himself claimed as predictions. Recall Harvey's postulate that a

⁷⁹ E. Zahar, 'Why did Einstein's Programme supersede Lorentz's?', *British Journal for the Philosophy of Science* 24 (1973), 103.

⁸⁰ See pp. 4-6.

⁸¹ See p. 9.

⁸² A. S. Lyons and R. J. Petrucelli, *Medicine: An Illustrated History* (South Melbourne: The Macmillan Company of Australia, 1979), p. 549.

⁸³ *Ibid.*, p. 557.

⁸⁴ *Ibid.*, p. 555.

⁸⁵ *Ibid.*, p. 561.

passage existed for blood to flow from the ends of the arteries into the ends of the veins: this was not corroborated until 1661 by Malpighi; and it was only in 1669 that Richard Lower (1631- 1691) corroborated Harvey's 'pulsific faculty' explanation of cardiac motion: Lower's work established that heart muscle itself controlled the heart's rhythmic movement.⁸⁶ Again in 1669, Robert Boyle (1627 - 1691) established that the difference in colour between purplish venous blood and scarlet arterial blood was due to venous blood being aerated in the lungs:⁸⁷ thus corroborating Harvey's idea that this difference was due to the 'straining effect' of lung tissue.⁸⁸

Thus, Harvey's theory predicted no type (i) or type (ii) novel facts which had been corroborated by the time this theory was generally accepted. Therefore on Lakatos' *criterion* one must conclude that (i) Harvey's theory did not progress, and (ii) consequently the change from Galen's theory to Harvey's theory was not rational.

We turn now to Thomas Kuhn's methodology. Can his ideas on scientific theory change account for the assumed rationality of the change from Galen's theory to Harvey's theory?

Let us begin with a brief exposition of Kuhn's views. For convenience we will separate them into two main sections.

Kuhn's Views on Scientific Theory Change

1. 'Paradigms' and the nature of argument in theory change

Kuhn sees theories as 'paradigms' having different world views, laws, exemplars, values and standards.⁸⁹ There is, then, little sharing of premises between competing theories and arguments for and against these theories are, as a result, inconclusive.

2. Early support for a new theory

Of the arguments for and against the competing paradigms, the ones most likely to be effective are those concerned with relative problem-solving ability.⁹⁰ However, although the new theory may solve some outstanding problems of the old, it still has outstanding problems of its own. This, combined with the fact that the older theory has a history of successful problem-solving, results in a balance of evidence favouring the old theory.⁹¹

⁸⁶ Neil, *William Harvey and the Circulation of the Blood*, p. 85.

⁸⁷ *Ibid.*, p. 86.

⁸⁸ Willis, *The Works of William Harvey*, pp. 114- 115.

⁸⁹ T. S. Kuhn, *The Structure of Scientific Revolutions*, 2nd edn., Foundations of the Unity of Science, Vol. II, Number 2, (Chicago: The University of Chicago Press, 1970). pp. 175- 191.

⁹⁰ *Ibid.*, p. 153.

⁹¹ *Ibid.*, p. 157.

This being the case, those scientists who do embrace the new theory at an early stage must do so as an act of faith - faith that the new theory will succeed with those many large problems that confront it while knowing that the older theory has failed only with a few.⁹² Moreover, sometimes this faith is based on highly personal and inarticulate aesthetic considerations such as the new theory being 'more suitable', 'more elegant' or 'simpler' than the old.⁹³

Criticism of Kuhn's Views

1. *Paradigms and the nature of argument in theory change*

The Riolan - Harvey debate is a general counter to the Kuhnian view of paradigms as competing, monolithic entities sharing little common ground. Recall that Riolan, despite his firm commitment to Galenism, adopted *in part* the Harveian 'law' that the blood circulates: for Riolan, blood circulated only in the major vessels like the aorta and vena cava.⁹⁴ Harvey's and Riolan's theories shared other elements besides; for example, both held as part of their 'world view' that knowledge could be gained from a detailed study of ancient texts in the light of personal observation and experimentation. Similarly, they shared Vesalius' superlative textbook of anatomy, *De fabrica humani corporis*,⁹⁵ as an 'exemplar' or guide to dissecting various parts of the body. Also the idea that the quantitative method was a legitimate, fruitful technique for solving anatomical and physiological problems was a 'value' common to both theories. Hence, the common ground cited here between Riolan and Harvey illustrates that competing theories can, contrary to Kuhn's idea, display significant overlap - which in turn opens the way to conclusive argument.

Turning now more specifically to the nature of argument, we will take up Kuhn's idea about there being too little sharing of premises and values for arguments to be conclusive. Such a view seems implausible as a component of the rationality of theory change: for if no argument can be conclusive for the new theory, it is difficult to see how the change from the old theory to the new theory can be rational, since rationality is concerned with argument and the giving of reasons. In any case, Kuhn's view does not square with the nature of argument in our case study. Of the many examples which could be cited,⁹⁶ two will suffice here.

⁹² *Ibid.*, p. 158.

⁹³ *Ibid.*, p. 155.

⁹⁴ See p. 13.

⁹⁵ Pagel, *William Harvey's Biological Ideas*, p. 158.

⁹⁶ For further examples see (1) the Harvey- Hoffman interchange of letters quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, pp. 231-252; (2) the Harvey - Riolan debate in Willis, *The Works of William Harvey*, pp. 87- 141; (3) the Gassendi - Fludd debate in Pagel, *William Harvey's Biological Ideas*, p. 114.

Our first example deals with a case concerning the shared premise that 'phenomena are constituted according to Nature'. Recall Harvey's argument from quantity and how it was supported with experimental evidence?' Against this, Galen's supporters argued that Harvey's findings were established in situations 'contrary to Nature': according to them, the heart in the process of dying during vivisection allowed blood to accumulate thus appearing to pump more blood than it actually did, and the fact that so much blood poured out of a cut artery was no proof to these Galenists that the same quantity normally goes through it. Thus, conditions in vivisection were to them different from those in the intact body.⁹⁸ To this objection Harvey replied that on *post mortem* findings, not on vivisectional findings, the amount of blood in the heart when dilated minus the amount contained when contracted equalled the amount expelled per beat, and therefore a great quantity of blood does pass through the intact body, which is 'constituted according to nature'.⁹⁹ Hence, Harvey had met his opponents on a common premise, and there is no reason to believe that Harvey's counter-argument was inconclusive.

The second example concerns the idea shared by both sides that personal observation and experimentation were crucial features of anatomical and physiological methodology. As we have seen, though Descartes supported Harvey's general circulation theory, he differed in his account of the cause of cardiac and blood motion:¹⁰⁰ for Descartes, the heart heated one or two drops of blood at a time causing them to rarefy and expand (much as when milk is boiled). This rarefaction and ebullition actively dilated the heart filling up its chambers and then-forcing the blood on its way into the arteries. This explanation, Descartes claimed, follows 'from the very disposition of the organs, as can be seen by looking at the heart, and from the heat which can be felt with the fingers and from the nature of the blood of which we can learn by experience'.¹⁰¹

To this, Harvey's supporter, Walaeus replied that no-one had ever observed blood to rarefy or to expand and claim more space. He then cited several of his own experiments on blood motion, the most notable being the following: in a strong dog when the apex of the heart was cut away, the ventricle was filled not more than half and yet the blood was forcefully ejected, not by any visible

⁹⁷ See pp. 6-8, 11-12.

⁹⁸ Whitteridge, *William Harvey and the Circulation of the Blood*, p. 131.

⁹⁹ Harvey, *An Anatomical Disputation*, pp. 85-86.

¹⁰⁰ For details of the disagreement between Descartes and Harvey see (1) J. Passmore, 'William Harvey and the Philosophy of Science', *The Australasian Journal of Philosophy* 36 (1958), 85 - 94; (2) R. Toellner, 'Logical and psychological aspects of the discovery of the circulation of the blood', in *On Scientific Discovery, Boston Studies in the Philosophy of Science*, Vol XXXIV, M. D. Grmek, R. S. Cohen and G. Cimino (eds.) (Dordrecht, Holland: D. Reidel, 1981), pp. 239-259.

¹⁰¹ Haldane and Ross, *The Philosophical Works of Descartes*, p. 112.

ebullition, but by the ventricle contracting.¹⁰² Thus Walaeus and Descartes argued on the common ground of appeal to personal observation and experimentation. Walaeus' argument was conclusive in that it provided adverse evidence which seriously challenged Descartes explanation of heart and blood motion; it demanded a reply which, however, was not forthcoming. These examples demonstrate significant common ground between the two theories and on this common ground arguments put by Harvey and his supporters effectively met their mark.

2. Early support for a new theory

We turn now to examine Kuhn's views concerning early support for a new theory.

Firstly, to say that scientists embrace the new theory against the burden of evidence provided by problem-solving is both misleading and simplistic: Kuhn's view neglects what seems an important distinction for the rationality of early support for a new theory namely that scientists can, with good reason, investigate the new theory without embracing it as if it were true.¹⁰³ Secondly, to then say that advocates of a new theory transfer their allegiance in faith sometimes based on highly personal and inarticulate aesthetic considerations seems an implausible account of the rationality of early support for a new theory, because such considerations are not likely candidates for what Lakatos would call 'good objective reasons'. In any case, Kuhn's account of the basis of early support for a new theory does not fit the Galen to Harvey theory change.

In 1636, for example, Johann Vesling (1598 - 1649) wrote to Harvey saying he had accepted as true Harvey's ideas on the origin, structure, and motion of the heart and function of the lungs because he had confirmed them by autopsy studies;¹⁰⁴ but he was reluctant to accept Harvey's view about the return of blood through the veins to the heart, since this conflicted with the results of his own embryological investigations. Vesling asked Harvey to clarify this issue. Unfortunately, Harvey's letters in reply are not known to have survived, but Vesling does tell us in a letter to a Paduan colleague that Harvey's letters had resolved his doubts and that consequently he accepted Harvey's theory *in toto*.¹⁰⁵

Johannes Walaeus in 1641 also found Harvey's theory to withstand empirical testing: his original arguments, observations and experiments

¹⁰² Pagel, *New Light on William Harvey*, p. 123.

¹⁰³ For further details on this distinction see L. Laudan, *Progress and its Problems* (London: Routledge and Kegan Paul, 1977). pp. 106- 114.

¹⁰⁴ Keynes, *The Life of William Harvey*, pp. 270- 271.

¹⁰⁵ *Ibid.*, pp. 270-271.

supported and augmented Harvey's findings;¹⁰⁶ for example, Walaeus arrived at quantitative results similar to Harvey's, and he found that this great quantity of blood pumped by the heart remained at the same level even in animals starved for several days;¹⁰⁷ this was further adverse evidence for Galen's idea that the liver produced blood continuously and in small amounts from digested food. Walaeus also demonstrated by means of vascular ligatures that blood circulated in all areas, notably in the spermatic, portal, coronary and jugular vessels.¹⁰⁸ Yet Walaeus held a critical allegiance to Harvey's theory, differing on some points and accepting some of Galen's on others. For example, whereas Harvey held that the heart's propulsive force moved the blood, Walaeus maintained that this force was supplemented in its work by the active dilation of arterial walls;¹⁰⁹ and with respect to the flow of blood from arteries to veins, Walaeus accepted the existence of both Galenic anastomoses and Harveian 'porosities in the flesh'.¹¹⁰ This last point about Walaeus illustrates that a scientist need not have a 'conversion experience'¹¹¹ from the old to the new theory, but may in fact continue to work on aspects of both theories until further evidence for or against either theory comes to light. Thus, anatomists such as Vesling and Walaeus came to support Harvey's theory early in the dispute not because of 'aesthetic preference' as Kuhn would have it but because Harvey's theory showed the following promising features:¹¹² (i) it had already offered plausible solutions to fundamental problems for Galen's theory (such as the nature and timing of cardiac motion); (ii) these solutions were independently testable and subsequently supported by test results. Moreover, (iii) the three component propositions of Harvey's theory were themselves testable and found independent empirical support;¹¹³ further (iv) Harvey's quantitation and his use of vascular ligatures¹¹⁴ were unprecedented as methods of anatomical and physiological research. They were both precise and fruitful. Walaeus, it will be remembered, had already provided a fully quantified account of digestion in terms of stomach acid, thus serving notice that Harvey's theory might well come to explain those phenomena (such as digestion and respiration) initially explicable only on Galen's theory. As well, (v) Harvey's methodology was resourceful: for

¹⁰⁶ As we have seen (pp. 15-17), Harvey's findings do not qualify as Lakatosian novel facts.

¹⁰⁷ Pagel, *New Light on William Harvey*, p. 118.

¹⁰⁸ *Ibid.*, p. 122.

¹⁰⁹ *Ibid.*, p. 125.

¹¹⁰ *Ibid.*, p. 122.

¹¹¹ Kuhn, *The Structure of Scientific Revolutions*, p. 151.

¹¹² For the notion of 'objective promise', see P. Urbach, 'The Objective Promise of a Research Programme', in *Progress and Rationality in Science, Boston Studies in the Philosophy of Science*, Vol. LVIII, G. Radnitzky and G. Andersson (eds.) (Dordrecht, Holland: D. Reidel, 1978), pp. 99-113.

¹¹³ See pp. 6-7.

¹¹⁴ On this point see (1) Pagel, *William Harvey's Biological Ideas*, p. 55, (2) Temkin, *Galenism*, pp. 14, 54.

example, his innovative criterion for a satisfactory explanation - 'establish the phenomenon first and then seek its purpose' - cleared the way for his supporters of 'much contradiction and elenchic argument'.¹¹⁵

Thus not only do Kuhn's views seem inherently implausible as an account of the rationality of theory change, but they cannot explain the assumed rationality of the change from Galen's theory to Harvey's theory.

We come now to present an alternative conception of the rationality of scientific theory change in light of the assumed rationality of the theory change from Galen to Harvey.

III

An Alternative Conception of the Rationality of Scientific Theory Change

What then is our conception of the rationality of scientific theory change? It consists in there being (i) good reasons throughout the period of change and (ii) a balance of good reasons in favour of the new theory by the end of the period of change.

Before we can substantiate this conception from our historical case study, some elucidation of 'good reasons' is required. We can achieve this by giving examples of what good scientific reasons are not.

A good personal reason for supporting a new theory may not necessarily be a good scientific reason: for example Robert Fludd (1574 - 1637) endorsed Harvey's theory early on in the dispute because it supported his own idea of there being a basic parallel between the cosmos and man with the former influencing the latter.¹¹⁶ He believed that it was only fitting that the blood circulated since this accorded with the pattern of circular motion exhibited in the heavens and in nature. Water, for example, had a cyclical repetitive motion from evaporation to rainfall and back to evaporation. Secondly, that Harvey had a great capacity for diligent and precise observation is a fact about Harvey's personality and no doubt played a part in Harvey's ability to construct his theory, but is not a good reason *for* Harvey's theory. Thirdly, to cite Harvey's position in society - he was physician to the King, and President of the London Royal College of Physicians - as a reason why Harvey's theory superseded Galen's theory is not to cite a good scientific reason: it is an

¹¹⁵ (i) Harvey, quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, p. 252, (ii) Harvey had in mind here arguments such as those concerning Galenic 'spirits whose nature was thus left so wholly ambiguous' that they served as 'the common subterfuge of ignorance' (see Willis, *The Works of William Harvey*, pp. 115-120).

¹¹⁶ Pagel, *William Harvey's Biological Ideas*, p. 115.

interesting historical fact but of no direct relevance to the status of Harvey's theory as a scientific theory.

Having given some examples of what good scientific reasons are not, we can now present the change from Galen's theory to Harvey's theory in terms of good reasons, thereby substantiating our conception of the rationality of scientific theory change. Our account will be divided into three sections:

- (1) good reasons elicited in the generation of Harvey's theory;
- (2) good reasons existing in the early stage of the dispute, and
- (3) a balance of good reasons in favour of Harvey's theory by the time it was accepted.

The Generation of Harvey's Theory

As we have seen,¹¹⁷ there were good reasons for Harvey to initiate his research. Firstly, Galen's theory was self-inconsistent: the heart valves, for example, were held to be both competent and non-competent. Moreover, on certain basic points Galen's theory was inconsistent with the view of more recent anatomists: for example, Galen held that i-v pores existed, whereas Columbus claimed they did not exist.

The fact that Harvey's investigations resulted in plausible solutions to fundamental problems for Galen's theory - for example, the problem of the exact nature and timing of cardiac motion - was a good reason for Harvey to continue his work.¹¹⁸ And the fact that Harvey *reasoned* his way to his idea of the circulation of the blood via a logical sequence of problem solving was a good reason for Harvey to treat his idea as a plausible hypothesis, worthy of further investigation.¹¹⁹

There were also good reasons for Harvey to rationally move from considering his idea as a plausible hypothesis to accepting it as if it were true: it was supported by his test results¹²⁰ and it also provided a unified explanation for a multitude of hitherto ill-explained and unconnected phenomena.¹²¹ Harvey's theory was then published and the period of theory dispute commenced.

Early Stage of Theory Dispute

1. *Reasons for Harvey's theory*

Early support for Harvey's theory was based on the following good reasons:

¹¹⁷ See pp. 3-4.

¹¹⁸ See pp. 4-6.

¹¹⁹ *Ibid.*

¹²⁰ See pp. 6-7.

¹²¹ See pp. 1-8.

(i) the independent testability¹²² of Harvey's solutions to basic problems for Galen's theory and of his three component propositions¹²³ - the logical sequence of problem-solving and the easy applicability and preciseness of the quantitative and ligature experimental methods facilitated Harvey's theory being independently testable; (ii) the independent empirical support gained by both Harvey's problem-solutions and his component propositions; and (iii) the provision of a unified explanation for hitherto unconnected, ill-explained phenomena. These good reasons in favour of Harvey's theory enable early supporters to rationally accept Harvey's theory while continuing to work on its outstanding problems.

2. *Reasons against Harvey's theory*

The fact that Harvey's theory did have outstanding problems was a good reason against it early on in the dispute.

The one-way passage of blood from arteries to veins demanded by Harvey's theory could not be demonstrated, and at this early stage Harvey offered no sound, independent argument for the existence of this passage. For example, in 1636 in reply to Hoffman, Harvey could say only that if one believed as Hoffman did in invisible anastomoses in the liver allowing blood to flow from the portal vein to the vena cava then there was no reason not to believe in 'porosities and invisible meanderings through the flesh'¹²⁴ (*i.e.*, capillaries). Another outstanding problem for Harvey's theory early in the dispute was that it could not adequately meet the accepted standard for a satisfactory explanation namely, 'one must establish both the phenomenon and its purpose'. As we have seen,¹²⁵ Harvey was certain that the blood circulated but he was, as yet, unsure of its purpose; and his innovative criterion for explanation - 'establish the phenomenon first and only then seek its purpose' - was untenable for many of his opponents at this stage.

So there was at an early stage of the dispute, room for rational disagreement, with there being good reasons both for and against Harvey's theory.

Acceptance of Harvey's Theory

We come now to the end of the dispute. Can our conception of the rationality of theory change accommodate this phenomenon of Harvey's

¹²² pp. 5-6. For the notion of independent testability, see K. R. Popper, *Conjectures and Refutations* (New York: Basic Books, 1962). pp. 33-39 and 215-220.

¹²³ See pp. 5 - 6.

¹²⁴ Harvey, quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, p. 251.

¹²⁵ See p. 11.

theory superseding Galen's theory by 1651? The answer is yes. There was a balance of good reasons in favour of Harvey's theory by this time. To depict this balance let us separate those reasons for and against both Harvey's theory and Galen's theory.

1. *Reasons for Harvey's Theory*

Harvey's theory had explanatory power: it provided, as we have seen,¹²⁶ a unified account of many and varied, hitherto unconnected and ill-explained phenomena - those observed in dissection, such as the difference in wall thickness between the right and left ventricles were accounted for;¹²⁷ *post mortem* findings such as the left ventricle and arteries being empty of blood and the veins being full of blood were also explained;¹²⁸ as well, events in medical practice, ill-understood on Galen's theory, became clear on Harvey's theory. Take blood-letting for example. Since blood flows to the periphery via the arteries and returns to the heart via the veins, it makes sense to apply a medium-tight ligature to the upper arm, thus allowing blood to enter through the arteries but preventing it from leaving through the veins. This blood can be drawn off easily from the distended forearm veins. But if, as Galen's theory holds, blood flows to the periphery via the veins, the veins proximal to the ligature should swell and blood should be taken easily from *these* veins; this, however, does not occur; and Galen's theory can offer only a most obscure account of blood-letting in terms of the ligature 'turning away' venous blood which retracts to the opposite side of the body.¹²⁹

Moreover, Harvey's theory had by this time satisfactorily explained the circulation's purpose. Harvey's reply, in terms of the blood imparting its lifesustaining heat to the body, was substantiated by Walaeus' comments:

Walaeus contended that since blood relinquished its life to the body tissues it required periodic rekindling, regeneration and purification by the heart. Furthermore, the rapidity of the circulation served to preserve the blood's freshness.¹³⁰

As well, those phenomena initially explicable only on Galen's theory could now be accounted for on Harvey's theory; gastric digestion for example, was now explicable in quantitative terms. Respiration could also be explained: on Galen's account it served to cool the cardiac fire and provide 'vital spirits' for arterial blood; but on Harvey's theory respiration functioned to cool the blood's innate heat and to 'strain' and thereby transform venous into arterial blood.

¹²⁶ See pp. 7-8.

¹²⁷ See p. 8.

¹²⁸ See p. 8.

¹²⁹ Pagel, *New Light on William Harvey*, p. 118.

¹³⁰ *Ibid.*, p. 128.

The second good reason for Harvey's theory is that his findings were independently testable and subsequently supported by the results of experiments and observations of other workers such as Walaeus, Vesling, and Slegel. Firstly, Harvey's solutions to fundamental problems for Galen's theory - the nature and timing of cardiac motion, its connection with the arterial pulse, the blood-flow through the heart and lungs, the i-v pores and so on¹³¹ - had all been supported by independent evidence; for example, on tying the pulmonary vein in live animals, Walaeus found that the part closest to the lungs became swollen and distended while the part on the cardiac side of the ligature collapsed.¹³² This evidence supported Harvey's idea of the pulmonary circulation. Secondly, the component propositions of Harvey's theory¹³³ were similarly checked and found to agree with the results of other workers' observations and experiments. For example, Harvey's proposition that blood returns to the heart via the veins was supported by Walaeus' experiment of ligating the vena cava above and below the heart and finding that in both cases the stretch of vein between the ligature and the heart emptied, and that the heart became pale and small.¹³⁴ One example of Harvey's finding being elaborated by others we have already met: a fully quantified, experimental account of gastric digestion attributed to acid.¹³⁵ Another is this. Walaeus applied Harvey's ligature method to show that chyle derived from the gut and flowed from here via the lacteal vessels into the general blood circulation.¹³⁶ Thus, the two good reasons in favour of Harvey's theory were its explanatory power and its being independently supported by the results of experiments and observations.

2. Reasons against Harvey's theory

Harvey's theory made no (Lakatosian) corroborated novel predictions.¹³⁷ It did predict novel facts in Lakatos' sense of 'novel', but as we have seen¹³⁸ these were not corroborated until after Harvey's theory was generally accepted. However, the force of this good reason against Harvey's theory is diminished by Harvey's vigorous attempts to lend empirical plausibility to these predictions. Two such predictions are of note.

Firstly, recall that a one-way flow of blood 'from the minutest arteries to the

¹³¹ See pp. 4-5.

¹³² Pagel, *New Light on William Harvey*, p. 117.

¹³³ See p. 6.

¹³⁴ Pagel, *New Light on William Harvey*, p. 117.

¹³⁵ *Ibid.*, p. 115.

¹³⁶ *Ibid.*, p. 116.

¹³⁷ For an alternative conception of novel fact, see A. Musgrave, (1) 'Logical Versus Historical Theories of Confirmation', *British Journal for Philosophy of Science* 25 (1974), 1-23, and (2) 'Evidential Support, Falsification, Heuristics and Anarchism', in G. Radnitsky and G. Andersson (eds.) *Progress and Rationality in Science*, pp. 181-186.

¹³⁸ See pp. 15-17.

finest veins' was necessary for the circulation to occur. But this blood flow could be seen neither by Harvey nor by his opponents. However, as we have seen¹³⁹ Harvey's treatment of this empirical anomaly was sound, providing independent argument based on observation and experimentation.

Secondly, Harvey predicted that the dark purple blood found in veins was the same as the bright scarlet blood found in arteries, and that the colour difference was due to the venous blood being 'strained through the pulmonary tissue'.¹⁴⁰ This 'novel fact' as we have seen¹⁴¹ was not corroborated until 1669. However, by 1651 Harvey had given experiments, observations, and arguments in support of this fact. He argued against the rival Galenic postulate that venous blood and arterial blood were two different kinds of blood, with arterial blood being more rarefied and ebullient, in the following way. Harvey shed blood from an animal's vein into one bowl and blood from one of its arteries into another bowl, filling each receptacle to the same height. Now if, as Galenists thought, the arterial blood was rarefied and effervescent, it would after cooling 'return to its original quantity of a few drops'.¹⁴²

However, this did not happen. In either basin Harvey found 'blood nearly of the same colour, not of very different consistency in the coagulated state, forcing out serum in the same manner, and filling the cups to the same height when cold than it did when hot'.¹⁴³ Secondly, one reason why Galenists believed in the diversity of arterial and venous blood was that it explained the post *mortem* emptiness of the arteries: after death the fermented, rarefied arterial blood returned to its original quantity of a few drops. However, Harvey had an alternative explanation - one in keeping with the results of experiments and observations: the left ventricle and the arteries appear empty 'simply because there is no supply of blood flowing round to fill them',¹⁴⁴ since the lungs collapse before the heart stops beating. The other reason for the Galenic belief in arterial blood being different in kind from venous blood was that the former had a more 'spiritous' nature causing its rarefaction and ebullition. Harvey's reply was two-fold. Firstly, he attacked the general notion of Galenic 'spirits'; this subject was for Harvey riddled with SO many conflicting opinions that it served as 'the common subterfuge of ignorance'.¹⁴⁵ Spirits were seen variously as 'aereal substances', 'powers', 'faculties' or 'virtues'. But Harvey could find 'none of all these spirits by dissection . . . of

¹³⁹ See p. 12.

¹⁴⁰ Willis, *The Works of William Harvey*, p. 115.

¹⁴¹ See p. 17.

¹⁴² Willis, *The Works of William Homey*, p. 114.

¹⁴³ *Ibid.*, p. 114.

¹⁴⁴ *Ibid.*, p. 115.

¹⁴⁵ *Ibid.*, p. 116.

living animals'.¹⁴⁶ As an alternative, Harvey offered the Hippocratic idea that 'spirits' were causes of activity.¹⁴⁷ Applying this idea to the specific problem of the spirit in the blood, Harvey maintained that spirit and blood flow as one, with the former being either the latter's 'act', or its 'agent'.¹⁴⁸ Spirit does not cause the blood to swell or ferment as is shown by the experiment on the bowls of arterial and venous blood: and in this respect, venous and arterial blood are the same.¹⁴⁹

Thus Harvey gave empirical plausibility to his prediction about the sameness of venous and arterial blood by offering sound 'ocular demonstration and logical argument' against the rival Galenic postulate and at the same time arguing vigorously for his own postulate.

3. *Reasons for Galen's theory*

The only possible contender for a good reason favouring Galen's theory by 1651 was that medicine was still being practiced within Galen's explanatory framework: physicians still thought in terms of Galenic 'humours' and of therapeutics in terms of blood-letting, purging and vomiting.¹⁵⁰ Yet, even if we admit this as a good reason for Galen's theory, Harvey's theory was a strong competitor on this ground as well. We have already seen how it could explain many medical practices such as the varied use of ligatures in blood-letting, amputation and removal of tumours.¹⁵¹ Also, other events in medicine such as the suppression or cause of haemorrhage, sloughing and gangrene, illexplained on Galen's theory, became easily understood on Harvey's theory.¹⁵² Moreover, with the general acceptance that blood circulated in the body, Galenic questions such as whether to bleed a patient from the same or opposite side of a disorder became irrelevant.¹⁵³

4. *Reasons against Galen's theory*

The explanatory power of Galen's theory was, by the end of the dispute, seriously weakened. It could account for the range of anatomical and physiological phenomena unified under Harvey's theory only in a piecemeal, disparate fashion. Moreover, many fundamental Galenic points had been strongly challenged by Harveian observation, experimentation, and argument: and it is in Galenic attempts to meet this challenge that we see how deficient

¹⁴⁶ *Ibid.*

¹⁴⁷ *Ibid.*, p. 117.

¹⁴⁸ *Ibid.*

¹⁴⁹ Whitteridge, *William Harvey and the Circulation of the Blood*, p. 192.

¹⁵⁰ Lyons and Petrucelli, *Medicine*, p. 434.

¹⁵¹ See p. 8.

¹⁵² Pagel, *William Harvey's Biological Ideas*, p. 56.

¹⁵³ Lyons and Petrucelli, *Medicine*, p. 434.

the explanatory power of Galen's theory had become. Let us take some examples.

Firstly, there was a mass of Harveian observational and experimental evidence against the Galenic belief in the existence of i-v pores.¹⁵⁴ Galenists such as Primerose, Hoffman and Riolan explained this counter-evidence in the following way: i-v pores could not be found on dissection nor could they be demonstrated experimentally because they close-up after death, but in life 'when the heart beats and is contracted and dilated when the pores in it in some manner also collapse and are dilated'.¹⁵⁵ This explanation was *ad hoc*: it was not independently testable, nor was it called for by any other findings, and it is difficult to see for what reason it could have been introduced if it was not solely to save a Galenic belief from strong counter-evidence.¹⁵⁶ Again, recall Riolan's adoption of Harvey's quantitative method:¹⁵⁷ from Riolan's premise that the heart pumped only one or two drops of blood per beat he concluded that only one or two circulations (through the major vessels) occurred per day. Riolan's premise was not based on any anatomical evidence (cf. Harvey's premise that the heart pumped no less than and probably more than one half ounce per beat, which was based on *post mortem* findings), and it was *ad hoc*. A third example is Riolan's explanation of Harvey's quantitative results, namely that the heart in the process of dying during vivisection allowed blood to accumulate thus appearing to pump more blood than it actually did.¹⁵⁸ This explanation was also *ad hoc*: since it denied the validity of the vivisectional experimental situation, how could it be independently tested?

Thus by the early 1650's Galenists had introduced quite a number of *ad hoc* hypotheses in an attempt to save their theory in the face of seriously adverse evidence.

The second good reason against Galen's theory was that all its testable claims were seriously challenged by rival observation, experiment and argument. The last articulation of Galen's fourteen-hundred-year-old theory was that of Riolan. Riolan, we will remember, tried an ingenious 'reduction' of Harvey's theory to Galen's theory. However, as we have seen¹⁵⁹ his attempted reconciliation was met at every turn by Harveian counterarguments. Riolan's general thesis that the blood circulated only through major vessels and not through intestines, limbs, or peripheral regions was

¹⁵⁴ (1) pp. 5 13- 14 (2) Pagel, *New Light on William Harvey*, p. 117, (3) Pagel, *William Harvey's Biological Ideas*, p. 114.

¹⁵⁵ Primerose, quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, p. 151.

¹⁵⁶ For the notion of '*ad hocness*', see (1) K. R. Popper, *The Logic of Scientific Discovery* (London: Hutchinson and Co., 1972), pp. 80-82, (2) C. G. Hempel, *Philosophy of Natural Science* (Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1966), pp. 28-30.

¹⁵⁷ See p. 14.

¹⁵⁸ See p. 19.

¹⁵⁹ See pp. 13-14.

shown by Harvey to be untenable; and Riolan's more specific claims such as the existence of i-v pores, the denial of a pulmonary circulation and the idea that the heart pumps blood a drop or two at a time were also seriously challenged.¹⁶⁰

A third reason against Galen's theory was that it predicted no novel facts which were subsequently corroborated. Indeed it predicted no novel facts at all: throughout the controversy, and especially toward the end, Galen's supporters were fully occupied in attempting to accommodate the new findings of Harvey's theory. For instance, Riolan's compromise was *post hoc* to its core, being formulated explicitly to show how 'the circulation occurs . . . without destruction of the ancient medicine'.¹⁶¹

The fourth reason against Galen's theory was that it was self-inconsistent. Of the many cases of this defect focussed on by Harvey, two examples from Riolan will suffice here. Firstly, Riolan claimed that blood-flow through the lungs was an 'impossibility'; yet elsewhere in the same book, *Enchiridium Anatomicum et Pathologicum*, he claimed that blood did indeed flow through the lungs.¹⁶² Secondly, Riolan asserted that blood circulated only in the major vessels like the aorta and the vena cava, but not in their small branches because in these smaller vessels blood was consumed as nourishment for the tissues; yet in other parts of his book, he claimed that blood did circulate in these smaller vessels; for example he stated that 'the brain by means of the circulation sends back blood to the heart and thus refrigerates the organ'.¹⁶³

So by 1651 there was the following 'balance-sheet' of good reasons. *For Harvey's theory*: explanatory power, and independent empirical support. *Against Harvey's theory*: none of its (Lakatosian) novel predictions corroborated, though certain of these predictions were made empirically plausible by Harveian observation, experimentation and argument. *For Galen's theory*: explanatory framework for medical practice, but Harvey's theory competing vigorously here. *Against Galen's theory*: lack of explanatory power with proliferation of *ad hoc* hypotheses; lack of empirical support; no corroborated novel predictions, only *post hoc* accommodation for new Harveian counterevidence; and internal inconsistency.

Clearly, there was a balance of good reasons in favour of Harvey's theory by the time it had superseded Galen's theory; it was thus rational for the scientific community to accept Harvey's theory over Galen's. We will conclude with one noteworthy consequence of our conception of the rationality of scientific theory change.

¹⁶⁰ See pp. 13-14.

¹⁶¹ Riolan, quoted in Whitteridge, *William Harvey and the Circulation of the Blood*, p. 182.

¹⁶² Willis, *The Works of William Harvey*, p. 99.

¹⁶³ *Ibid.*, p. 96.

The Context of Discovery vs the Context of Justification

The explanation of the rationality of scientific theory change in terms of there being good reasons throughout the period of change challenges a distinction prominent in the philosophy of science since the 1930's, namely the distinction between the context of discovery and the context of justification. In its standard formulation,¹⁶⁴ this distinction divides the history of a new theory into a discovery period (before the theory is on hand) and a justification period (the subsequent testing of and giving good reasons for that theory). The former period, it is claimed, contains no guide, no rational plan of research, being 'merely a long preliminary process of trial and error';¹⁶⁵ it is therefore of no relevance to the understanding of scientific rationality (a rationality which is asserted to feature exclusively in the fully articulated, published versions of theories). However, this notion of the period of scientific discovery is not borne out by our case study: recall that Harveian research from the start was focussed on and guided by fundamental problems for Galen's theory;¹⁶⁶ and the fact that Harvey's theory was grounded in plausible solutions to these problems was a good reason in its favour. In its generation then, Harvey's theory had a rationality it would not have had if it had been generated *de nova* (having no connection with its predecessor).¹⁶⁷ This component of the rationality of Harvey's theory superseding Galen's theory is ignored by the discovery/justification distinction and by those philosophers such as Lakatos who adhere to it.

Our conception of the rationality of theory change substantiated by the Harveian case provides an argument against the context of discovery/context of justification distinction as a basis for an adequate understanding of the rationality of scientific theory change - a rationality which has been elucidated in terms of there being good reasons throughout and a balance of good reasons in favour of the new theory by the end of the period of change.

¹⁶⁴ For different forms of this distinction see T. Nickles, 'Introductory Essay: Scientific Discovery and the Future of the Philosophy of Science', Vol. LVI (Dordrecht. Holland: D. Reidel, 1980), pp. 1-60.

¹⁶⁵ Lakatos, *Criticism and the Growth of Knowledge*, p. 133n.

¹⁶⁶ See pp. 3-4.

¹⁶⁷ On the close relationship normally existing between successive theories, see T. Kuhn, 'The Halt and the Blind: Philosophy and History of Science', *British Journal for the Philosophy of Science* 31 (1980). 181-192.

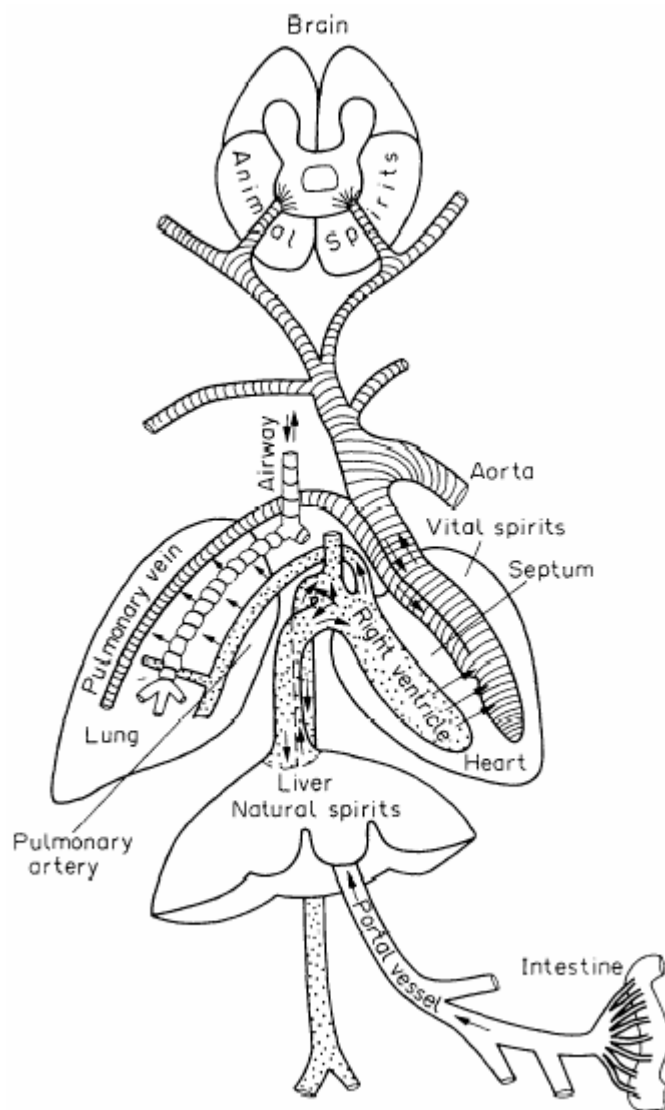


Figure 1. Galen's system of the heart and blood movement.

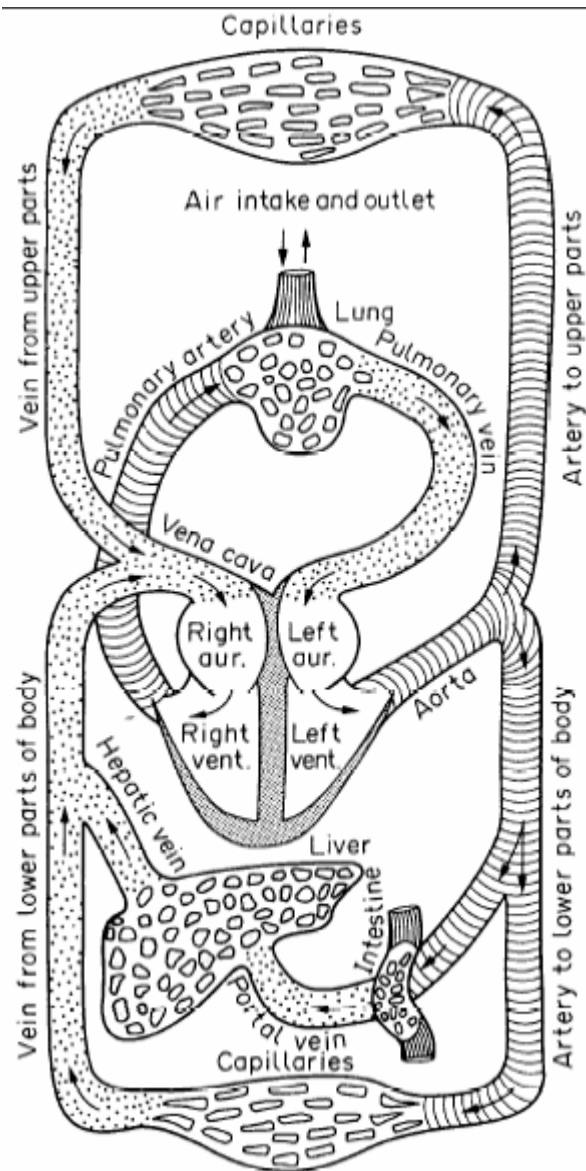
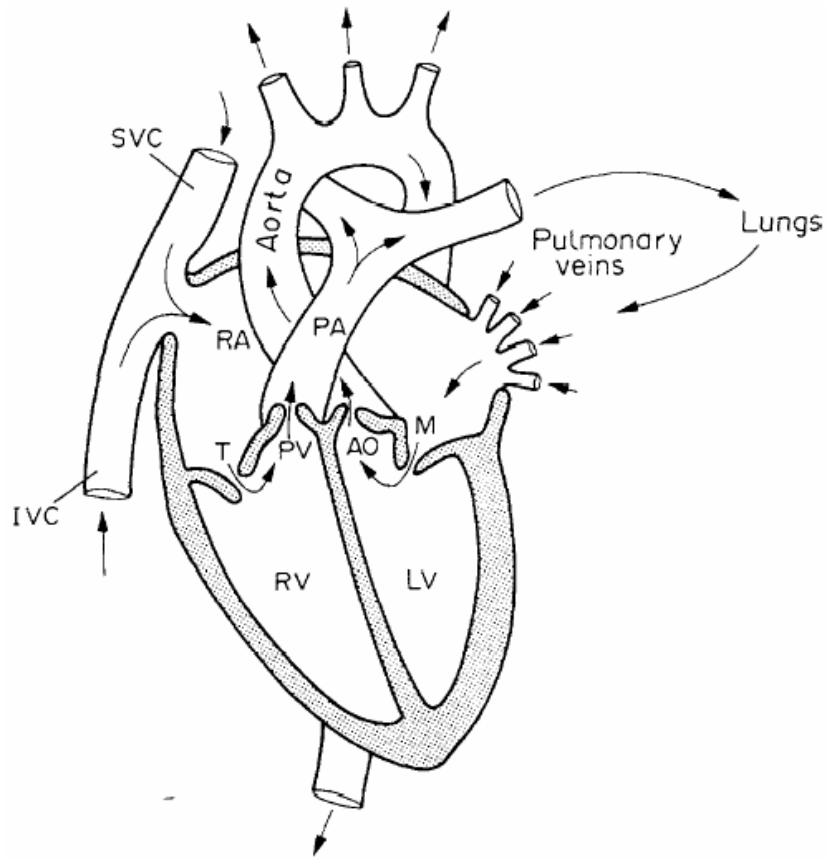


Figure 2. William Harvey's system of blood circulation.

Head and upper extremities



Trunk and lower extremities

- | | |
|--------------------------|-----------------------|
| svc - Superior vena cava | PA - Pulmonary artery |
| IVC - Inferior vena cava | PV- Pulmonary valve |
| RA - Right atrium | M-Mitral valve |
| T -Tricuspid valve | LV - Left ventricle |
| RV - Right ventricle | AO – Aorta |

Figure 3. A modern diagram of the heart and major arteries and veins.