

**THE TRIUMPHAL MARCH OF A PARADIGM:
A CASE STUDY OF THE POPULARIZATION OF NEWTONIAN SCIENCE***

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*"To see a World in a Grain of Sand
And a Heaven in a Wild Flower"*
William Blake

Introduction

The history of the popularization of science still awaits its historiographer. Popular science seems today to be a stepchild of 'high' science, and its history forms no part of the history of science proper. Science was up until recently considered by historians to be the business of male adults specially trained to deal with it, and no business of females, children or, in general, uneducated people. The views propounded by popularizers, and lay notions of scientific knowledge, seem not to count and may well be ignored according to those historiographers of science who indulge themselves in 'rational reconstructions' of the development of science. "They regard the history of science as primarily the arena of rational thought and experiment and wish to pursue rational explanations as far as it will go," says Mary Hesse,¹ and "As Steven Shapin has emphasized, all too often historians have treated the diffusion of science as a passive process involving the transfer of knowledge from areas of 'high truth concentration' to those of 'low concentration'."²

The transmission of scientific knowledge to an uneducated public has been considered as an, in principle, unilateral, one-sided process involving no reaction on the part of the target audience and thus eliciting no reaction from science itself.

* This paper is a somewhat abbreviated and improved version of a paper contributed to the symposium "Después Newton" held in Madrid. I would like to express my gratitude to the editors of *Tractrix* for their valuable help in making the text more readable and less sweeping in its statements. All the remaining possible mistakes or controversial assertions are, however, mine.

¹ M. Hesse, "Socializing Epistemology," in *Construction and Constraint. The Shaping of Scientific Rationality*, ed. E. McMullin (Notre Dame, Indiana, 1988), p. 105.

² J. Secord, "Newton in the Nursery: Tom Telescope and the Philosophy of Tops and Balls, 1761-1838," *History of Science* 23, 1985, pp. 127-151, on p. 128.

That is, the relation between high science and low (or popular) science was conceived of as a strictly asymmetrical causal relationship and not essentially an interaction. This was one of the main reasons for the neglect of popular science by historians of science. Another reason was that the history of science was construed as the progress towards increasing truth and validity, while the *acceptance* of scientific knowledge was considered as a matter of course to be *self-explanatory*. It is only quite recently that science has been put back into its social context and that the problems of *validity* and of *acceptance* are considered as not necessarily identical. That is to say, the new science may or may not have been closer to the truth than its rivals – this feature alone does not exhaust explanations for its eventual triumph. Techniques of persuasion – of propaganda even – were involved, too. As Alistair Crombie writes in his latest programmatic paper,

in the whole scientific movement considered in the context of society and of communication, *persuasion has been as important as proof*. The use of persuasive arguments to reinforce or to create the power of ideas to convince, especially when the ideas were new and the audience uncertain or unsympathetic, has been well understood by some of the greatest scientific innovators. Galileo and Descartes were both masters of the current rhetorical techniques of persuasion.³ [Italics mine, M.F.]

My aim in this paper will be to point out and to discuss through the example of one, in many respects typical eighteenth-century popular science book, some important means and techniques of persuasion which were used to promote the acceptance of Newtonian science by contemporaries, both laymen and scientists. The scope of this contribution, however, does not permit me to enter into the even more important and interesting questions of how the process of the popularization of science affected science itself, i.e., what (if any) influence this process exerted upon scientific results and methods, and how it may have changed the rate of scientific development.

Some issues in the popularization of early modern science

Science nowadays enjoys as a matter of course an amount of institutional support that, in the seventeenth and eighteenth centuries, had to be conquered before it could be enjoyed. That conquest – what may be called the popularization of science – begins with Galileo, who was the first to turn to a new lay audience in order to gain support for his new, revolutionary scientific ideas and to win his battle against traditional cognitive authority. The new science created a new public for itself, by turning to the laymen and discounting thereby the number and intellectual power of its possible enemies. (Descartes was, pace Crombie, more restricted and conservative than Galileo in this respect. He addressed himself

³ A. Crombie, "Designed in the Mind: Western Vision of Science, Nature and Mankind," *History of Science* 26, 1988, pp. 1-12, on p. 6.

– like the Aristotelians – only to his fellow scholars, even trying to evade direct confrontation with his intellectual enemies, but never thought of attempting to make an ally of the laymen in the paradigm debate.)

Early modern science was thus born together with its twin brother: popular science – later on so greatly despised. The popularization of scientific knowledge was the price to be paid for public support and social recognition, especially since victory in the battle between different paradigm contenders for intellectual power over men's minds were at stake here. Ascension to the rank of a paradigm or dominant view of the world for a scientific theory needs more than just endorsement by specialists or experts in the strict sense. This is and was necessary but insufficient. To gain dominance, the theory in question has to pervade almost all forms of life, including the arts and politics, theology and everyday conversation. It has to become part and parcel of enculturation, of all forms of discourse beginning with the nursery school, continuing into sophisticated salon conversations and church sermons. It also has to inculcate itself into the minds of ordinary people. It has to create a highly homogeneous space of ideas and their objectifications (forms of discourse, works of art, structures of argument, etc.) – a kind of Popperian third world, where scientific textbooks, paintings, pieces of music, and poems, as well as the schoolmaster's handbooks, can coexist and mutually reinforce each other's message.

This was precisely what happened to Newtonian natural philosophy during the first half of the eighteenth century. If Newton's conception of the universe became, within a generation, a part of the outlook of educated men, it was not because they had read the *Principia*. No, this was due to a process of pervasive persuasion alongside the ongoing process of pure argumentation among the experts. During this process of popularization (the word being understood in a much wider sense than it is today) a whole choir of different voices was singing – if not in unison, then at least in amazing harmony – the praise and glory of Newton and his ideas, or rather, of the ideas attributed to him and earmarked by his name. His views were explained⁴ and distorted, defended and refuted,⁵ preached⁶ and criticized,

⁴ E.g., by such men as Henry Pemberton (*A view of Sir Isaac Newton's philosophy* (London, 1728), translated into French, Italian and German); Voltaire (*Éléments de la philosophie Newtonienne* (Amsterdam, 1738), translated into English by J. Hanna in the same year); or by W.J. 's Gravesande (*Physices elementa mathematica, experimentis confirmata* (Leyden, 1721), translated into English and French) – to mention only a few of the best known and the earliest.

⁵ E.g., by Tomasso Campailla who in 1728 published dialogues in Italy confuting Newtonian physics by du Perron de Castera, a French Cartesian, who published his *Diverses objections contre le système newtonien* in 1726 at Nuremberg; or by Jean Banières, in his *Examen et refutation des elemens de la philosophie de Newton et de Voltaire* (Paris, 1739); or, indirectly, by Cardinal Polignac, in his *Anti-Lucretius ...* (Paris, 1732). Newton's ideas and his methodology have been powerfully defended – on the other hand – against the attacks of John Hutchinson, an English clergyman, by George Horne, Bishop of Norwich in his *A fair, candid and impartial state of the case between Sir Isaac Newton and Mr. Hutchinson ...* (Oxford, 1753).

⁶ E.g., in the Boyle lectures preached between 1692 and 1713. Especially in the sermons held by Richard Bentley in 1692-1693 ("A confutation of atheism from the origin and frame of the world"). Cf. J. Dahm, "Science and Apologetics in the Early Boyle Lectures," *Church History* 39, no. 2, 1970.

admired and ridiculed,⁷ praised and condemned,⁸ glorified and depreciated. The Newtonian views spread with amazing speed and within two generations reached nurseries⁹ and the ladies' boudoirs and such far away countries as Russia, America and Japan.¹⁰

The decisive battle for Newtonianism had been won among, and with the help of laymen, especially members of the aristocracy and the bourgeoisie. Without proliferating names, let me mention only a few less well-known examples. Prince Menshikoff, a Russian nobleman who, in 1714, applied for fellowship of the Royal Society and was graciously granted admission by Newton himself (though the good prince had no academic merits whatever). However, this was a world where even the Tzar, Peter the Great, felt it was his duty to pay tribute to Newton's excellence in 1698 while the monarch, who had formerly attended Boerhaave's lectures in Leyden, was staying in London.¹¹

This was an age in which another monarch, George III of England, was proud of his nickname of 'Farmer George', because of his having published papers on agriculture. It was also an age in which, conversely, commoners were knighted for their academic merits and scientific achievements, as was Newton himself for instance, and many others, including the hero of the second part of the present paper, Francesco Algarotti, the son of an Italian merchant, who was made Count Algarotti by Frederick the Great of Prussia.

The Royal Society opened its membership to commoners, noblemen and clergymen, irrespective of rank and position. Science was at this time on the way to taking over the place formerly occupied by religion and to become the leading ideology – a new secular religion, with its cult objects, pantheon of saints, rituals of worship, and central dogmas of faith. Among the legion of propagandists for

⁷ E.g., by Swift in *Gulliver's Travels*, especially in the chapter on the voyage to Laputa. Cf. M. Nicolson and N. Mohler, "The scientific background of Swift's Voyage to Laputa," in *Fair Liberty was all his Cry, a Tercentenary Tribute to Swift*, ed. N. Jeffares (1976; originally *Annals of Science*, 1937). However, most artists admired Newton without any reservation. Cf. F. Wagner, *Zur Apotheose Newtons* (München, 1974).

⁸ E.g., by the English poet William Blake. Cf. M. Nicolson, *Newton demands the Muse: Newton's Opticks and the Eighteenth-Century Poets* (London, 1946); D. Ault, *Visionary physics: Blake's response to Newton* (Chicago, 1974).

⁹ Cf. Second (n. 2), "Newton in the Nursery."

¹⁰ Cf. V. Boss, *Newton in Russia: the early influence, 1690-1796* (Cambridge, Mass., 1972). The first Newtonian was J. Bruce (a Russian nobleman of Scottish origin), the director of the School of Mathematics and Navigation, who was entrusted by the Tsar to translate Newton's *Principia* into Russian. As for America, cf. D. Gjertsen's *The Newton Handbook* (London, 1986), p. 381, where he writes: "The first book to appear in America, written by an American, to show some comprehension of Newtonian mechanics, was probably *The Christian Philosophy* (1720) by Cotton Mather." More important however, was the early influence exerted on Benjamin Franklin by John Keill, a disciple of Newton, who in 1710 came to America and got into touch with the American scientist. John Keill's *Introductiones ad veram physicam* has been translated into Japanese by Shizuki Tadao, and published in 1802 under the title *Rekisho Shinsho*. Cf. Gjertsen, *The Newton Handbook*, p. 385.

¹¹ According to Boss (n. 10), *Newton in Russia*, pp. 9-15, it is very unlikely that Peter the Great did actually meet Newton while staying in London.

Newtonianism there were some, most notably Jean Théophile Desaguliers¹² (the son of a French refugee Huguenot priest) who was eager to supply the ideology for this alliance between science and the ruling elites. Desaguliers was among the first (Voltaire, Rousseau and Adam Smith following suit) to exploit the Newtonian philosophy of nature for explicitly ideological purposes. The very title of Desaguliers' allegorical poem candidly professed the author's claim; it runs as follows: "The Newtonian System of the World, the Best Model of Government." (It was published in 1728 and dedicated to George I.)¹³

According to Desaguliers, liaison officer between scientists and laymen, the Cartesian Sun "governs by fear [i.e. by geometrical necessity – like an absolute monarch], instead of love [i.e. attraction]" as the Newtonian Sun, the paragon of a constitutional monarch. He tried to convince his readers that the Newtonian philosophy of nature can serve as the metaphysical foundation of the new political regime, the constitutional monarchy. Desaguliers "made explicit what the people in London felt and wanted to hear ... The equilibrium of forces in nature, the unimpeded validity of its laws and the marvellous harmony in the universe fascinated them and pervaded their whole personality."¹⁴ In Newton Britain celebrated itself and its rising political and economic power. The British Society willingly recognized itself in the mirror of Newtonian science, or rather it was eager to identify its idealized self-image in it. On the other hand, science also rejoiced over its role as the metaphysical cornerstone of society. As his correspondence testifies, Newton himself gladly accepted most of the moral and theological consequences drawn from his scientific works (and even modified his utterances in later editions

¹² Desaguliers studied Newtonian physics at Oxford with John Keill. In 1730-1734 he published his *Course in experimental physics* in 2 volumes (London). "Desaguliers' experimental confirmation of Newton's (optical) results played a central role in convincing the doubters on the Continent," writes H. Guerlac (*Newton on the Continent* (Ithaca, New York, 1981), p. 128).

¹³ Let me quote a few lines from Desaguliers' allegorical poem:
 "But now my cautious Muse consider well / How nice it is to draw the parallel: / Nor dare the action of crown'd heads to scan / (at least within the memory of man) / ... / Nor let the whims of the Cartesian scheme / In politics be taken for thy theme,"
 Because Descartes' vortex theory, which Desaguliers calls a "physical Romance," is:
 "Condemned in England but believed in France / For the bold Britons who all tyrants hate / In Science as well as in the State / Examined with experimental eyes / The vortices of the Cartesian skies / Which tried by Facts and mathematick Test / Their inconsistent principles confess'd / ... / But Newton the unparallel'd whose name / No Time will wear out of the Book of Fame / ... / This tow'ring Genius, from its certain cause / Ev'ry appearance a priori draws / And shows the Almighty Architect's unalter'd Laws / That Sol self-pois'd in aether does reside / And there exerts virtue far and wide / Like Ministers attending ev'ry glance / Six worlds sweep round his Throne in mystic dance / He turns their motion from its devious course / And bends their orbits by attractive force / His power coerced by Laws, still leaves them free / Directs but not destroys their Liberty. / ... / And reigning thus with limited Command / He holds a lasting scepter in his Hand / By his example in their endless race / The primaries lead their satellites / Who guided, not enslaved their orbits run / Attend their chiefs, but still respect the Sun / Salute him as they go and his dominion own."
 (J.Th. Desaguliers, *The Newtonian System of the World, the Best Model of Government* (London, 1728), pp. 20-37).

¹⁴ F. Wagner, *Isaac Newton im Zwielicht zwischen Mythos und Forschung* (München, 1976), p. 24.

accordingly). It is in this way that the implicit ideological message¹⁵ of Newtonian physics and metaphysics becomes partly explicit.

The fact that Newton's philosophy of nature could serve as the ultimate metaphysical and moral justification for constitutional monarchy (and even, as it turned out later on, of the constitutional republic in the case of the American Constitution)¹⁶ reinforced the acceptance of scientific results, as well as giving self-assurance to politicians and to citizens in general. The outcome of the whole process was a strengthening of the alliance between science and civil society, and a feeling of mutually beneficial cooperation.

In a society where, as in early eighteenth-century England, the seat of excellence began to shift from aristocracy by birth to aristocracy by intellectual eminence (i.e., from aristocracy to meritocracy) and where the former ruling class lost part of its power or, rather, had to share it with another wider, newly emergent class, the bourgeoisie, the pursuit of knowledge within the traditional (clerical) framework also lost part of its privileged position. It ceased to be an advantage that it was the concern of only the initiated few, the Schoolmen. Thus the task of new, early modern science was to gain popularity among uninitiated laymen, the intellectually powerless majority, because it was in need of a supportive power in its fight against old, Aristotelian established science. The emergent bourgeoisie, on the other hand, could also benefit from a new science, in a twofold, ideological and economic sense. A new profession or vocation had thus to emerge in the social division of labor: that of the popularizer of science, who served as a mediator between science and the lay public. The popularizer played the role of merchant in the market of ideas, mediating between the producer and consumer of intellectual goods. This was the process in which the new science created its own public.

The popularizer serving as an interface between science and the non-scientific sphere had to adjust his activity and its product to the needs of both parties and thus convey a message in both directions; shaping science on the pattern of lay modes of reasoning, and shaping the lay mind-set on that of science. An image of science had to be given to laymen, which science had, willy-nilly, to recognize as a self-image, while inducing laymen to conform to their usually flattering idealized intellectual image, i.e., to that of the 'intelligent lay person' whose intelligence manifests itself in the very act of accepting the scientific theory conveyed to him by the popularizer.

With Galileo as his own popularizer, we are in a period *before* the separation

¹⁵ When speaking about this implicit or underlying ideological message, I am relying on Gideon Freudenthal's studies in his *Atom and Individual in the Age of Newton* (Dordrecht etc., 1986), in which he sets up, and argues for the thesis "that Newton's principle on the relation of element and system was affected by the development of civil society" (p. 196).

¹⁶ Cf. I.B. Cohen's talk prepared for the History of Science Society meeting in Raleigh, October 1987, under the title *Science and the Constitution*, where he says: "the evidence declares that no constitution would have been acceptable if it seemed to contradict the Newtonian philosophy or the accepted principles of science, that the Newtonian philosophy and science in general formed an important part of the background of thought of many who were concerned with producing a blueprint for the American future" (Ms. of the talk, p. 23).

of tasks began. With Newton, the social division of labor unfolding, we see the tasks of *creating* and of *popularizing* science distributed among different people. A new era begins.

Parallel to the campaign led by devotees of the new science against the old, Aristotelian science, there were struggles going on *within* the new science as well. These were fought by the different paradigm contenders for intellectual hegemony. By the end of the seventeenth century the emphasis had shifted almost wholly to this latter kind of battle, and the formerly unanimous fight against Aristotelianism gave way to fights among representatives and devotees of different new scientific schools and theories, such as Cartesians, Leibnizians and Newtonians. This situation created completely *new tasks* for popularizers and required the latter to introduce *new methods*. Even a *new kind of audience* had to be targeted.

While formerly, i.e., during the war against Scholastic science (up until the end of the seventeenth century) the target audience consisted (or was tacitly assumed to consist) of male, adult members of the higher classes – noblemen, in general; recall again Galileo's Sagredo – by the end of the seventeenth century, a year before the *Principia*, there appears Fontenelle's *Entretiens sur la pluralité des mondes* (1686) in which, for the first time, it is a *lady*, the Marquise G. who plays the role of the ignorant but open-minded and intelligent lay-person. By the middle of the eighteenth century (with the 1761 appearance of "Tom Telescope")¹⁷ even children were being included in the possible target public for popular science.

By widening the audience, science extended its influence and tightened its grip on society, thereby gaining greater support from those influenced; and by extending its influence, science at the same time increased its own fecundity, i.e., increased the scope of possible proselytes among whom it could recruit future candidates for the scientific elite. The benefits which, in addition, accrued to society (or at least to some social strata) through a general increase of its intellectual level can only be mentioned here in passing.

Algarotti's *Il Newtonianismo per le dame*

My main concern in the remainder of this paper will be to discuss the way in which a particular theory within early modern science – the Newtonian – underwent a process of popularization; the form in which it could be embraced by laymen; the process of persuasion; the methods and techniques employed by popularizers. In short: how popularization contributed to the victory of Newtonianism over its rivals, Cartesianism and Leibnizianism; and how its paradigm characteristics were

¹⁷ At that time in England a book was published, entitled *The Newtonian system of philosophy, adapted to the capacities of young gentlemen and ladies*, a book which – as James Secord writes: "could be advertised as a 'Philosophy of Tops and Balls'. This tiny gold-covered volume was ostensibly the published result of scientific lectures at the Lilliputian Society delivered by an enterprising (if imaginary) lad named Tom Telescope" (Secord (n.2), "Newton in the Nursery," p. 127). "Tom Telescope's lectures came from the press (and probably the pen) of John Newbery, a London bookseller active during the middle years of the eighteenth century" (*ibid.*, p. 129).

emphasized and even supplied by popularizers.

To accomplish this task I have chosen only one such book for discussion. It is Francesco Algarotti's *Il Newtonianismo per le dame*. It is my contention – which can only be confirmed or disproved by further studies to be made in the history of eighteenth-century popularization of science – that, as 'in a grain of sand', one can see the whole universe of popular science in Algarotti's book. Like Pemberton's, Voltaire's and other less well-known authors' books, Algarotti's book was among those which paved the way for the triumphal march of Newtonianism all over Europe. Algarotti's *Il Newtonianismo per le dame* (the complete title being: *Ovvero, dialoghi sopra la luce, i colori e l'attrazione*) had been extremely popular among the author's contemporaries. It was republished in each of six subsequent years after its first appearance in 1737 (in Milan),¹⁸ the 16th edition of it appearing as late as 1812. It was translated almost immediately into several languages, including French, English, German, Russian and Portuguese.¹⁹ (Unfortunately, I have no knowledge of a possible Spanish translation.)

The author Francesco Algarotti was a man of great erudition, well versed in, and publishing papers on the arts and sciences, and standing in high esteem with the most eminent scholars of his time in his home country, Italy, as well as in France, in England, in Prussia, and also in Russia, where he spent more than a year. Voltaire, with whom he stayed in Madame du Châtelet's palace while writing *Il Newtonianismo per le dame* in 1736, described him as "brillant et sage, à qui le ciel a départi l'art d'aimer, d'écrire et de plaire"²⁰ (a brilliant and sage man, whom the heavens presented with the art of loving, writing and pleasing). Having finished his book on Newtonianism, Algarotti was even invited by Maupertuis to participate in his Lapponian expedition to check some of the predictions in Newton's theory of gravitation. Algarotti, however, went instead to London, then to Saint Petersburg

¹⁸ *Il Newtonianismo per le dame* appeared, according to its frontispiece, in Naples, but according to Algarotti's biographers it was in fact published in Milan. Cf. E. Bonora ed., *Illuministi Italiani*, vol. 2: *Opere di Francesco Algarotti* (Milano/Napoli, 1969), p. 11; and Ch. Dedeyan's Introduction to Algarotti's *Lettere sulla Russia* (Paris, 1959).

¹⁹ The first French edition appeared as early as 1738 (Paris) in the translation by du Perron de Castera; the first English version came off the press in 1739 (London) in the translation by Elizabeth Carter. "It was fitting," writes Marjorie Nicolson, "that as a woman – Aphra Behn – had translated Fontenelle's *Conversations on the Plurality of Worlds*, for her countrywomen, so Elizabeth Carter translated Fontenelle's Italian successor" (M. Nicolson, *Newton demands the Muse: Newton's Opticks and the Eighteenth-Century Poets* (London, 2nd. ed., 1963, p. 27). A second English edition of *Il Newtonianismo* came out in 1742 (London). This was also attributed to Elizabeth Carter, but it seems to be an essentially different translation to me. (The name of the translator is not indicated on the front page.) Nicolson is of the same opinion: "My opinion is," she says, "that it is an entirely different work, by another translator" (*ibid.*, p. 17). I have no idea who the translator might have been. The first German translation was published in 1745 (without place of publication) by Johann Meintel under the title *Newtons Welt-Wissenschaft für Frauenzimmer oder Unterredungen von dem Licht, von den Farben und von der anziehenden Kraft*. A Dutch edition appeared under the title *De Newtoniaansche wijsbegeerte voor de vrouwen of samenspraaken over het licht, de kleuren en de aantrekkingskracht* (Amsterdam, s.d.). I have no data concerning the first Russian translation of the book, except that Algarotti expresses his thanks to Prince Cantemir for translating it, in the Preface of the second (1739) Italian edition of his book.

²⁰ Cf. Voltaire's poem prefixed to the second (1739) Italian edition of *Il Newtonianismo*.

(1762-1764) and to Berlin. In spite of his rather short lifespan and the great variety of places in which he lived, and his circumstances at different periods, he was very prolific as a writer; his *Collected Works* as published after his death (1791-1794) consist of seventeen thick volumes containing papers on arts, sciences, politics and economics.

I have studied and compared six different editions of Algarotti's *Il Newtonianismo* – two Italian, two French and two English – in the library of Princeton University.

Cartesianism versus Newtonianism

What struck me most about this book is that, in it, I could trace a significant document of the fight for intellectual hegemony between the main paradigm contenders of the time: Cartesianism and Newtonianism. Algarotti's book is thus intentionally polemic, serving as a weapon in this battle. The author expressly tells us that he intends his book to be a counterpart to Fontenelle's *Entretiens*, i.e., he has written his *Newtonianism for the Ladies* to counterbalance the influence formerly exerted upon them by Fontenelle in favor of Cartesianism, and to demonstrate the supremacy of Newtonianism. In the Preface to his book (which he dedicates to Fontenelle) Algarotti admits to following the example of the French author as far as literary form, techniques of persuasion and stylistic means are concerned, but announces that his main purpose is to undermine the greatest achievement of the *Entretiens*: the Cartesian conviction it was meant to induce in its readers.

In other words, Algarotti's purpose is not merely to popularize Newton's theories and to make them accepted by lay persons, but also to induce his readers to *reject* Cartesianism. Thus he not only argues *for* Newton but at the same time *against* Descartes, whereas Fontenelle was merely propounding Descartes' cosmology but not arguing against rival conceptions. Furthermore, he depicts Descartes and his theories as not only opposed to Newton's but as *inferior* to them. So he does not merely reject Cartesianism; he depreciates it as well, e.g., by calling it a "philosophical romance"²¹ or by accusing Descartes and his disciples of coining "imaginary systems,"²² conjuring up "phantoms" which have "deluded our sight" and which can be "dissipated only by the light of Newtonianism."²³ This is expressed in a picturesque and concise manner in the poem by B. Stillingfleet, the English Newtonian, prefixed to the second Italian edition²⁴ of Algarotti's book:

²¹ F. Algarotti, *Sir Isaac Newton's Philosophy Explain'd for the Use of the Ladies, in Six Dialogues on Light and Colours*, 2 vols. (1st ed., London, 1739), vol. 1, p. 50.

²² *Ibid.*, vol. 2, p. 18.

²³ *Ibid.*, vol. 2, p. 247.

²⁴ F. Algarotti, *Il Newtonianismo per le Dame, ovvero Dialoghi sopra la luce, i colori e l'attrazione* (2nd ed., Napoli, 1739).

See, She [the Truth] appears, and Fiction quits the Place
 The subtle Phantom vanishes away
 And to the rightful Queen the Scepter yields.
 Too long usurped, no Refuge now remains
 To screen her from Confusion: down she sinks
 Lost in the Ruins of her Vortices.

It is remarkable, therefore, how the French translator of *Il Newtonianismo*, du Perron de Castera, who is an anti-Newtonian (and who published a booklet in Latin in Nuremberg in 1726, making diverse objections to Newton's theory of gravitation, giving two of these in his Foreword to the French edition),²⁵ tries to restore Descartes' reputation by construing an evolutionary model for the development of knowledge, and representing Descartes as a *forerunner* and *not a rival* of Newton, one whose knowledge was less than, but not inferior to Newton's. "Quel reproche peut-on faire à Descartes?," he asks, "S'il n'a pas développé tout, c'est la faute du temps, ... l'expérience et les observations lui manquèrent ..." According to de Castera, Descartes' work paved the way for, rather than hindered, the appearance of Newton's theories. "Descartes est le Masaccio de la Physique," he says, "Peut-être que sans lui Newton n'aurait su que bégayer,"²⁶ i.e., Descartes is to Newton, as Masaccio is to Raphael.

This is a very significant difference indeed between the standpoints of the belligerent Newtonian and the defensive Cartesian. The latter is trying to diminish the clash between the two rivals, the older and newer paradigms, and to maintain the illusion of absolute *continuity* by a typical evolutionist argument. Conversely, the former emphasizes discontinuity by pointing out their differences, and tries to set up an hierarchical ranking order between them.

Making Newtonianism fashionable and promulgating it among women proved to be a very clever and powerful means of persuasion to be used by Algarotti. In the first decades of the eighteenth century, Newtonianism needed to be popularized and made fashionable. In England and elsewhere in Europe Jacques Rohault's manual of Cartesian physics, translated by Samuel Clarke in 1697 from French to Latin, continued to be the standard text in philosophy instruction as late as the 1720s. Rohault's work was then translated into English in 1723, the third edition appearing in 1735. Cartesianism was popular even among the Cambridge Platonists, Joseph Glanvill being among those who translated (1688) Fontenelle's *Entretiens* into English. Newtonian natural philosophy made its first official entry into the place of its birth, so to say, by the back door: the translator of Rohault's book, Samuel Clarke – a committed Newtonian – affixed notes to the book which were

²⁵ In the *Avvertimento* of the second (1739) Italian edition of his book Algarotti reflects upon the French translation. His comment on de Castera's above described practice is: "Iddio gli perdoni le sue Note e le sue Novelle ..."

²⁶ F. Algarotti, *Le Newtonianisme pour les Dames, ou Entretiens sur la Lumière, sur les Couleurs et sur l'Attraction*, traduit per du Perron de Castera (2nd ed., Paris, 1739), p. ix.

a virtual refutation of the text.²⁷

"It is curious," writes Marjorie Nicolson, "that Henry More, for example, never mentions Newton's theories of optics, since he himself was interested in the subject and long after he departed from his early allegiance to Cartesianism in general, continued to teach Descartes' *Dioptrics*."²⁸ There was also rather strong opposition to Newton's optical theory among scientists elsewhere in England at the turn of the century. Hooke's and Huygens' views were, for a long while, more favorably received, which discouraged Newton for a time from further publication.

So we must not think that a paradigmatic theory destined to become victorious is able to prove its own merits, even for the scientific community, by rational means alone. We must also recall that – as Kuhn has pointed out – the winner theory is better than any of its rivals *only* according to its *own* standards. This is eminently true in the case of Newton's physics. It seemed by no means superior to Descartes' for most of the contemporaries. As is well-known, the Newtonian system was theoretically highly controversial mainly because of the occult gravitational force. The popularization of Newtonianism was thus in no way a superfluous undertaking, either from the standpoint of its future victory or from that of its further development. Popular demand, which involved a technological-economic demand, contributed to its conceptual clarification, and constituted a challenge to scientists to find further practical applications for it.

A female audience

A second and no less important feature of Algarotti's book, which in my view made it most eligible for discussion, is that the author addressed himself to "the ladies," i.e., to a female audience. So he targeted the same audience as Fontenelle, albeit two generations later. To do so was thus no pioneering enterprise at that time, but it was not yet a very common one. He was also following Fontenelle's example in keeping the dialogue form of the *Entretiens*, instead of writing a more scientific-looking treatise on Newtonian physics, as Voltaire and other popularizers did. The *Newtonianismo* consists of six conversations between the author and a Marchesa di F., which makes the difficult task of explaining high-level scientific notions and assumptions to a laywoman more vivid, exciting and much easier. Fontenelle assumed his heroine the Marquise G. to be completely ignorant concerning even basic scientific knowledge, "a person who understood nothing of natural philosophy,"²⁹ so his aim was to tutor her in Cartesian cosmology. Algarotti assumes the Marchesa to be conversant with Cartesianism (i.e., he assumes that Fontenelle's

²⁷ Cf. Guerlac (n. 12), *Newton on the Continent*; J. Saveson, "Differing reactions to Descartes among the Cambridge Platonists," *Journal of the History of Ideas* 21, 1960, pp. 560-567.

²⁸ Nicolson (n. 19), *Newton demands the Muse*, p. 7, n. 11.

²⁹ B. le Bovier de Fontenelle, *A Plurality of Worlds*, translated by J. Glanvill (London, 1688), p. 6. There are several other English editions of the *Entretiens*, published in 1753, 1761, 1767, 1777, etc.

enterprise was successful) and his purpose is to convert her to Newtonianism. By targeting the ladies, and assuming them to be better educated than they could in fact have been, Algarotti proves to be an extremely clever popularizer. He created a flattering, though unreal, and highly idealized image; the urge to conform to this image could and should have been the aspiration not only of the spiritually best women of his age but even of the most fashion conscious. With his elegant dialogues he succeeded in making Newtonianism *fashionable* among the female members of the higher classes. By making it a matter of fashion he moved the ladies to develop – or at least to pretend to have developed – an ardent commitment to it, affecting in this way, if only indirectly, their husbands and friends as well. Nor were these men the sole targets at one remove, for not only the *boudoir*, but also the *salon* was a place Algarotti must have had in mind in addressing himself to a female audience. Many readers he aimed at ran *salons* of their own, and here was an important possible source of patronage to be gained for the new science. By converting the head of a *salon* to Newtonianism, Algarotti might secure important sources of material support for that novel enterprise in search of wealthy patrons.

The tradition among aristocratic women of being, or at least pretending to be, well versed in the newest developments in the kingdom of ideas, mainly in the arts, goes back to as early as the second half of the seventeenth century in France, and the 'ladies' were imitated by well-to-do bourgeois women. The especially mindless versions of this attitude had already been ridiculed by Molière in his "Les Précieuses" and in "Les Femmes Savantes." In the first decades of the eighteenth century it was part of *bon ton* in sophisticated salons to extend this versatility from the arts to the fundamentals of the sciences as well.³⁰ How fashionable this kind of spiritual decoration was, can be inferred from – among others – Maurice Quentin de la Tour's famous painting (1753) representing Mlle Ferrand,³¹ a young bourgeois woman with all the paraphernalia of wealth and social rank, meditating over a book popularizing Newton, most probably Voltaire's *Éléments de la Philosophie de Newton*. This scenery shows the extent of Newton's popularity as well as the rapidity with which the study of books popularizing his views became a kind of symbol for social standing, even for the women of the higher classes. For instance the Abbé Nollet, whose popular *Leçons de physique expérimentale* (1735) explicated for the French reader Newton's experiments on color, gave lectures to the Dauphin

³⁰ Algarotti complains about how the Italian ladies are lagging behind their French counterparts: "If we except some translations from the French, there is nothing among us but songs and collections of verses, which every day overspread us like a deluge and are the torments of our age. In the modern books, written in the Italian language, the Ladies can find nothing but sonnets full of metaphorical love, which I suppose must affect them as little as an antiquated expression of superannuated cicisbei" (Algarotti (n. 21), *Sir Isaac Newton's Philosophy*, vol. 1, p. xvi). He adds: "I have at least opened the way to something which is neither Grammar, nor Sonnet ..." and "I have brought into Italy a new mode of cultivating their [i.e., the Ladies'] mind, rather than their hairdress and placing their curls" (*ibid.*, vol. 1, pp. xiii-xiv).

³¹ I owe this example to Fritz Wagner. Cf. his *Zur Apotheose Newtons* (n. 7), p. 6.

in 1744 which were frequently attended by the Queen and the Dauphine.³² This shows that the extension of fashionable interest in the arts to natural philosophy was well under way by the middle of the century. This trend was partly created, reinforced, and exploited by Voltaire and by Algarotti whose book was, not very surprisingly, more popular in France than in Italy.

'Forced to embrace Newtonianism'

In the third place, let me point to another important peculiarity of *Il Newtonianismo per le dame*, namely that it is expressly meant for inducing a paradigm change or – as Kuhn puts it – *Gestalt-switch* in the Marchesa and all other possible readers of the dialogues. Unlike Fontenelle formerly, later Voltaire and other popularizers, whose aim was to replace ignorance by knowledge of Cartesian and Newtonian physics respectively, Algarotti aimed at *changing* a conviction concerning natural philosophy assumed to be already well-entrenched. The *Newtonianismo per le dame* is also different in this respect from Galileo's *Dialogue*, because in the latter the main antagonist Simplicio ends up on the Fourth Day roughly where he began, i.e., he is not supposed to be converted to the new science,³³ while the Marchesa di F. undergoes a complete paradigm switch by the end of the Sixth Dialogue. In one of the last sentences of his Dialogues, Algarotti announces to the Marchesa that: "The light of Newtonianism has dissipated the Cartesian phantoms which deluded your sight. You are now really a Newtonian and it is no small advantage to Truth that you are so."³⁴

Algarotti seems to be well aware of what exactly he is going to undertake, since he declares – in a surprisingly Kuhnian way – that

I have made a sort of change or Catastrophy in the philosophy of my Marchioness who is at first a Cartesian, afterwards a Proselyte of Malebranche, and at last obliged to embrace [*forzata d'abbracciare* in the original; *forcée d'embrasser* in French] the system of the Person, who ought to be placed at the head of the Species, if superiority and rank among Mankind were determined by the Strength of Genius, and the most comprehensive knowledge.³⁵

The fact is, however, that the Marchesa appears to be very docile, and yields very easily to the author's persuasive efforts; she even asks to be converted: "Achevez,

³² Cf. Guerlac (n. 12), *Newton on the Continent*, p. 163 seq.

³³ It is interesting and thus worth mentioning that a Signor Simplicio turns up eventually in Algarotti's *Newtonianismo*. He is, however, not an Aristotelian as is Galileo's Simplicio, but a snobbish, conceited poet, who appreciates only poetry and is unwilling to become well versed in matters of natural philosophy. He parts company with the Marchesa and the Author when they ridicule and laugh at him. Cf. mainly the last and final version of 1752 (Berlin), in Bonora (n. 18), *Illuministi Italiani*, vol. 2.

³⁴ Algarotti (n. 21), *Sir Isaac Newton's Philosophy*, vol. 2, p. 247.

³⁵ *Ibid.*, vol. 1, p. viii.

je vous prie, s'écria la Marquise, de me rendre Newtonienne; je vois bien que par ma conversion j'acquiers la connoissance de la vérité sans perdre le plaisir que je trouvois dans les ingénieux mensonges de la philosophie Romanesque."³⁶

Means of persuasion

The arsenal of Algarotti's persuasive means is also worth attention. First of all, he is amazingly careful to make and emphasize the distinction between 'us' and 'them'. He keeps the Marchesa and thus the reader continuously aware of how wrong she would be if she accepted the Cartesian explanation of the optical and gravitational phenomena discussed in the book, of what it is that 'we', clever, enlightened people, free from prejudice and relying on experimental observations hold to be true, as opposed to what 'they', the wrong-headed 'system builders' think, who indulge in fantasies and romances, lacking any empirical evidence and never getting close to truth. This kind of depreciation of the intellectual enemy is a very powerful psychological means if you want to put new ideas into the heads of people who are less susceptible to arguments than to persuasion. This is what Algarotti takes women to be, as he says in the Preface: "I have endeavoured to render truth, without appealing to the support of demonstration, agreeable to that Sex, which had rather perceive than understand."³⁷

I want to emphasize, however, that Algarotti's method of persuasion is never crude or unsophisticated; he uses logical as well as psychological means, and he raises arguments against the enemy alongside depreciating qualifications. Depreciation of Cartesianism for its anti-empiricist epistemological standpoint belonged to the standard Newtonian rhetoric at even the highest scientific levels, so it was not specific to popular science. Yet if you want to discard old convictions and elicit new commitments, you have to be clever in mingling different high- and low-level methods.

Another example of this is that Algarotti presents Newtonian optics as common-sensical and the paragon of sound reasoning. He causes the Marchesa to 'discover' on her own the foundations of Newton's theory of vision, after, of course, it has been pointed out to her how wrong the Cartesian assumptions are.

Algarotti is ingenious in taking his examples from contemporary everyday practice as illustrations of Newtonian theory, thereby rendering that practice permeated by Newtonianism, and moving ordinary people to see their surroundings through Newtonian spectacles. For instance, when propounding the Newtonian theory of colors his examples are such everyday things as the pink powder on the cheeks of the Marchesa, the colors of the paintings on the walls in her palace, and

³⁶ Algarotti (n. 26), *Le Newtonianisme pour les Dames*, p. 50.

³⁷ Algarotti (n. 21), *Sir Isaac Newton's Philosophy*, vol. 1, p. v. In the original and in the French translation, instead of "perceive" and "understand," we find the words "sentire" and "sapere," "sentir" and "savoir" respectively.

so forth. In this way he succeeds in transforming even the everyday lay understanding of common perception and permeating it with a Newtonian interpretation.

Algarotti is also ingenious in explaining away the most common and well-known objections to Newtonian optics in a way which is only partly correct, but very easily understandable to the lay public. The question was why the early repetitions of Newton's famous prism experiments – performed among others by Mariotte, Pardies, Dortous de Mairan and Algarotti himself – did not succeed in leading to the same results as Newton's, i.e., in the neat separation of the differently refrangible light rays. According to Algarotti the failures were due to the poor quality of the prisms produced and used for this purpose, and the less accurate way in which the experiments were performed in France and in Italy. As he tells the Marchesa, the prisms produced in Italy had been used thus far only for decorative purposes and for entertainment, as interesting toys without scientific interest. This in fact accounts for at least some of the failures, and moves the experimenters to look for better prisms.

Algarotti's common sense substracts nothing from, but rather adds to the effect exerted on lay audiences by his book which, while popularizing science, purports to be entertaining. As the author writes: "Whatever the success of this undertaking, the Ladies for whom this work is principally intended, ought at least to think themselves obliged to me, if I have procured them a new kind of amusement which others may perhaps carry to a greater perfection."³⁸ Indeed, he aims to arouse in the reader the joy of knowledge and the pleasure of using one's own head. He shows how enjoyable it can be to discover great truths about the universe. Yet he admits that: "The Sanctuary of the Temple will always be reserved for the Priests and Favourites of the Deity; but the Entrance and its other, less retired Parts will be open to the Profane." Thus, while arguing for the thesis that Newtonianism corresponds to common sense and is comprehensible for everybody, he preserves the charismatic character of science and the scientist. A finely balanced stance!

With this we are at a turning point in the history of modern science – at a point where we can locate incipient new elitism. In the first half of seventeenth-century early modern science, unlike Hermeticism and Scholastic natural philosophy, was not at all secretive or restricted in its accessibility to only a few specially trained individuals, the elite. The new science was at that time advertised as rather common-sensical and in principle open to anyone, since its epistemic warrants rested ultimately on the sorts of logical calculation and empirical observation that were accessible to any rational individual with some, but *not special* training.

The formation and separation of a scientific elite ("the priests and favourites of the Deity") began only during the first half of the eighteenth century. This is also the period when the separation of 'high' science (high culture) and 'low' (i.e., popular) science (culture) begins.

Without becoming abstract, tedious and unintelligible for the lay reader,

³⁸ *Ibid*, vol. 1, p. xiii-xiv.

Algarotti also thus succeeds in transmitting very important implicit social messages.

This practice is made explicit when Algarotti considers the consequences of Newtonian physics for the arts and politics. Optical discoveries – he points out for instance – have greatly contributed to the advancement of painting techniques, and have even widened the scope of artistic vision.³⁹ More important, however, is the fact that Algarotti, like Desaguliers earlier, is eager to show how beneficial the acceptance of Newtonianism is, or can be, for the improvement of politics and the social order in general. After eloquently describing and explaining the assumptions of Newtonian natural philosophy, as well as the empirical observations supporting it and resulting from it, he puts the rhetorical question

is not Policy indebted to these for that wise and real Government which renders the Southern Suns [i.e., Italy] less pleasing than the Cloudy Regions of the North [i.e., England] where the liberty of the people is made compatible with the superiority of the Nobles and the authority of the Sovereign.⁴⁰

He, too, relies on the well-known analogy between the king and "The Sun who notwithstanding his vast size is subject to the general force of gravity [and] may serve for an example to great kings, whom neither the extent of their fortune, nor the superiority of their station can ever exempt from an observation of the universal laws of humanity."⁴¹

The prevalence of optics

Remarkably, in five out of the six dialogues comprising the second and later editions of the book, and the whole of the first, the author deals exclusively with optics; only in the sixth dialogue does he briefly treat the fundamentals of the Newtonian theory of gravitation. Thus Algarotti was popularizing that part of Newtonian physics which was already somewhat known and popular, as well as more easily comprehensible to the lay public and even to the scientists themselves. As Henry Guerlac showed, even in France, where there was prolonged opposition to Newtonianism, a French translation by Pierre Coste of the *Opticks* was available as early as 1720. Yet I.B. Cohen has discovered in Paris an incomplete and abridged French translation from as early as 1704, which he attributes to the physician and chemist Etienne François Geoffroy.⁴² "The discussion of colour in a popular book [P. Polinière's *Expériences de physique* (Paris, 1709)] on experimental physics was profoundly altered between 1709 and 1718," argues Guerlac. "During this interval, in 1712 Malebranche had come to accept Newton's description of his experiments

³⁹ Algarotti (n. 24), *Il Newtonianismo*, p. 17.

⁴⁰ Algarotti (n. 21), *Sir Isaac Newton's Philosophy*, vol. 2, p. 17.

⁴¹ *Ibid.*, vol. 2, p. 203.

⁴² Cf. Guerlac (n. 12), *Newton on the Continent*, p. 76.

and his revolutionary doctrine of color."⁴³ In Paris Dortous de Mairan – after many failed efforts – successfully repeated Newton's optical *experimentum crucis* which members of the aristocracy also witnessed. Later, others repeated this famous experiment. They included Jean Trichet and Gaston Granger; Cardinal Polignac, himself an arch-anti-atomist and opponent of Newton's cosmological assumptions, was present as well as d'Agessseau, the Cancellor of France.⁴⁴

Besides the interest in Newtonian physics among scientists, there was an equally strong interest among the men of arts, especially among poets, as this was heralded by Richard Glover (in his poem prefixed to Henry Pemberton's *A View of Sir Isaac Newton's philosophy* of 1728) when he announced "Newton demands the Muse."

The mission of Algarotti and those like him was thus to arouse and also to reinforce already existing interest in Newtonianism among laymen. For this purpose optics was more appropriate than the theory of gravitation, not least because the optical phenomena were of more immediate concern for them and because the *Opticks* was written and first published in English and not in Latin.

Yet, although Algarotti finished his book in France, i.e., in a country greatly sympathetic to his views and his enterprise, he nevertheless conceived the idea of the book and had actually published it first in his home country, Italy, the most unlikely place in contemporary Europe to endorse Newtonianism, especially cosmology. This brings me to the final feature of *Il Newtonianismo per le dame* to which I want to draw attention.

Algarotti's success, even in Italy

This feature is that, considering the most unfavorable, even hostile intellectual climate (the Italian) and the least interested and understanding audience (the ladies) for which it was intended, Algarotti's book proved to be amazingly successful (let us remember, it was published six times in subsequent years after its first appearance in Italy alone), and it brought fame and reputation to its author in his home country. Early eighteenth-century Italy may have indeed seemed the most hopeless place in which to try to popularize Newtonianism, since it was a very backward country, divided by internal political controversies, and the last stronghold of dogmatic, counter-Reformation Catholicism, in which Copernican astronomy was banned (until 1835) and Galileo's trial was well remembered after even a hundred years. It was a country in which the general public could have been expected to consider Newtonianism as an especially dangerous kind of heresy invented by an arch-Protestant, anti-Trinitarian heretic. "Besides," writes Algarotti, "Sir Isaac Newton's system came from a country too far beyond the Alps to be favourably received among Italians. It would be very surprising if a system produc-

⁴³ *Ibid.*, p. 138.

⁴⁴ *Ibid.*, p. 141.

ed in England had not been treated with aversion by some persons in this country.⁴⁵ It was especially dangerous because it claimed that heliocentric astronomy was demonstrable, i.e., compelling reasons were given for it which were as yet lacking from Galileo's *Dialogue*. However, surprisingly, only in the sixth (1746) Neapolitan edition of Algarotti's book do we find the editor (Eredi Hertz – the heirs of Hertz) cautiously prefixing the following announcement: "quanto si dice, nel presente libro riguardo al moto della Terra, si deve pondere come Ipotesi astronomica, non come asserzione dell'Autore, il quale venera, come convien a un buono Cattolico, i Sacri Decreti e le decisioni che si hanno contro il Sistema Copernicano" (what is said in the present book regarding the motion of the earth, must be considered as an astronomical hypothesis, not as an assertion of the author, who venerates, as becomes a good Catholic, the sacred decrees and the decisions that have been ordained against the Copernican system). The author, however, disguises nothing of his true opinion concerning the ideologically vital points of Newtonianism, irrespective of any traditional authority and of the multitude of opponents. Algarotti does not seem to be afraid of any persecution, or even of the possible lack of success for his book. The triumphal march of Newtonianism was going on all over Europe and no force was strong enough to keep it in check anymore – not even in Italy and Russia⁴⁶ where opposition to Newtonianism was the strongest. This, in my view, testifies to the popularity and power over men's minds acquired by the Newtonian Science during the first half of the eighteenth century.

Summary

The paper addresses a problem area that is rarely taken up in the historical literature – the popularization of science. With Algarotti's 1737 *Il Newtonianismo per le dame* as a case study, the author attempts to show how important a role such a popular book could play in shaping the mentality of the lay public. Topics to be discussed include Algarotti's methods of persuasion; the historical setting in which several different editions of his book could come out in different languages; its influence in converting scholars and laymen to Newtonianism (or in France, to turn them away from Cartesianism).

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⁴⁵ Algarotti (n. 21), *Sir Isaac Newton's Philosophy*, vol. 2, p. 52.

⁴⁶ Algarotti's opinion concerning these countries is none too flattering. He writes: "Galileo might truly be called the Czar of Philosophy. That people among whom Peter the Great introduced the arts and sciences differed very little in character from those whom Galileo attempted to reform. No one people ever used such endeavors for knowledge as the Muscovites did to know nothing, and to continue in the most scandalous ignorance. Their laws prohibited the foreigners to enter their country and the inhabitants to leave it. Thus it was with these Philosophers who, jealous of their tenets, renounced every experiment and more certain demonstrations of the moderns, rather than to introduce any novelty or reformation into their systems; but as force has generally more influence upon men than reason, the Czar compassed his designs sooner than Galileo" (*ibid.*, vol. 1, pp. 29-30).