

## Contents

List of illustrations	
Preface	
Footnote abbreviations	xxvi
I The making of the natural philosopher	
<ul> <li>1 From the ashes of revolution         Ireland in rebellion: 1798         The Battle of Ballynahinch and a dissenter's education fixed the liberal values of James Thomson.         The Belfast Academical Institution: 1814–32         While professor of mathematics at this radical, latitudinarian institution, James Thomson developed his views on progressive, practical, democratic education.</li> </ul>	3 4 9
2 Clydeside Glasgow and the Clyde Between 1800 and 1840 Glasgow changed from a commercial town to an industrial city, where modernizing entrepreneurs and progressive university	20 21
professors met in the Glasgow Philosophical Society.  The University of Glasgow  Only gradually did the forces of change, symbolized by new regius professorships, overcome the conservative College oligarchy.	25
The new mathematics professor  Dr Thomson brought with him from Belfast in 1832 his reform programme for mathematics education.	32
John Pringle Nichol: the education of the people  As a brilliant astronomy lecturer, latitudinarian radical, and close friend of the Thomsons, Nichol added excitement and daring to the whig values of the family.	37
Dr James Thomson: 'latitudinarian' and university reformer Dr Thomson led the movement of the whig faction to abolish the 'tests' in the 1840s.	41
Dr Thomson's family Raised and educated by their father, the Thomson children made his values and goals their own.	49
3 A Cambridge undergraduate Of a liberal education	56 58

vii



viii Contents

	At Cambridge, 'liberal education' did not carry the democratic, practical, and professional emphasis of Glasgow liberalism.	
	Father and son	68
	Economy in all things, avoidance of waste and dissipation, epitomize the moral and social virtues that Dr Thomson constantly stressed.	
	Towards graduation	76
	William concluded his Cambridge training as winner of the Silver Sculls, Second Wrangler, and First Smith's Prizeman.	
4	The changing tradition of natural philosophy	83
	The laws of nature	84
	Scottish tradition in natural philosophy emphasized God's active agency in nature and the intimate relation of knowledge and power.	00
	Politics and progression	89
	A changing context for both natural and social philosophy in the 1830s demanded a new accommodation between liberal ideology and natural law. Politics and pedagogy: the campaign for succession	99
	William Thomson's election to the chair of natural philosophy marked a	,,
	major victory for the whig reformers of Glasgow College.	
5	Professor William Thomson	117
	The practice of natural philosophy	120
	The new professor treated precision measurement and mathematical	
	expression as the refined instruments of a practical art.  Early years of the physical laboratory	128
	The first physical research labratory in a British university would serve	
	simultaneously the needs of natural philosophy and of industrial development.  Human fragility	135
	From 1847 to 1852 William Thomson's secure family life was wracked by	
	death, religious turmoil, emigration, unrequited love, and a problematic marriage.	
	II The transformation of classical physics	
6	The language of mathematical physics	149
	Reformers of the first generation	151
	Mathematical reformers of Dr Thomson's generation originally idealized Lagrange's algebraic analysis and Laplace's static solar system as symbols of	
	progress and order in systems governed by natural law, both physical and	
	political.	
	Opposing styles and a skewed reception	155
	During the 1830s the reformers recaptured traditional British emphases on geometrical analysis, non-hypothetical theory, and practicality, which they recognized in the methods of Fourier and Fresnel.	
	Whig mathematicians of the second generation	168
	At Cambridge William Thomson joined a younger group of reformers who	



	Contents	ix
	created a new mathematics – the operational calculus – and a newly professionalized consciousness.  Progression and kinematics  Two concerns closely related to the operational calculus circulated in the Cambridge network: a progressionist view of the earth and solar system; and a separation of the geometry of physical motions from their causes, or kinematics from dynamics.	192
7	The kinematics of field theory and the nature of electricity Electrostatics: the analogy to heat flow Geometrical analogy allowed mathematical theorems about electrostatic	203 203
	force to be proved from physical reasoning about the motion of heat.  Mathematical theorist meets experimental theorist: Thomson and Faraday  Disparagement turned to admiration as mathematical power bowed to	212
	physical insight.  Inductive capacity and the quantity-intensity distinction  Thomson's attempt to reconcile contiguous action with action at a distance through the analogy with heat flow reveals enduring differences between Thomson's and Faraday's (also Maxwell's) views on the nature of electricity and propagated action.	219
	The latitudinarian theorist and the practical imperative  The kinematics of field theory exhibits methodological and ideological commitments typical of the Thomson family in its Glasgow context.	228
8	The dynamics of field theory: work, ponderomotive force, and extremum conditions What makes an electrified body move? From 1843 Thomson developed the idea that the ponderomotive force on an electrified body is an action of the surrounding air—ether.	237 238
	Mechanical effect, mathematically and practically: the steam engine as metaphor Conceiving an electrostatic system as an engine made capacity for work its defining feature, radically transforming ideas of ponderomotive force, absolute measurement, and force distribution.	240
	Field theory proper Magneto-optic rotation, understood by mathematical analogy with the straining of an elastic solid, and diamagnetism, understood through conduction of lines of force, made a reality of fields containing work.	257
	The hydrodynamic analogy The dynamics of fields, as a dynamics of extremum conditions, emerged from interaction with Stokes over a fluid-flow analogy to magnetism.	263
	Practical considerations and 'positive' theory  Magnetic field theory exhibits the ideal of unity of theory and practice that would dominate Thomson's career.	276
9	Thermodynamics: the years of uncertainty  Prelude to 'the dynamical theory of heat': the Thomson brothers  Long-time puzzlement about losses of available work in engines and a	282 285



x Contents

	sophisticated elaboration of Carnot's theory of the motive power of heat preceded William's and James's reception of Joule's researches.  The Joule-Thomson debates: 1847-50  Conservation posed no problem; interconversion did, because it violated the directionality of natural processes.	302
10	Thermodynamics: the years of resolution The beginnings of thermodynamics: Rankine, Clausius, and Thomson Tentative acceptance of the dynamical nature of heat, and of the	317 318
	interconvertibility of heat and work, depended on interaction with Rankine.  The establishment of classical thermodynamics  Full acceptance of interconvertibility required a new understanding of	327
	directionality through a religiously grounded dissipation axiom.  The dynamical theory of heat	333
	The assertion that if heat is not matter it must be motion reveals the character of Thomson's mechanical philosophy and recasts the problem of heat as the problem of molecular force.	
	The watershed: molecular energy physics The dynamical theory of heat brought with it a new programme of unified physical theory based on energy relations.	341
11	T & T' or Treatise on Natural Philosophy The collaboration	348 349
	In five impassioned years Thomson (T) and Tait (T') produced a <i>Principia</i> to replace Newton's, based on energy not force, continuum mechanics not hard atoms, and practical abstractions not microscopic models.	
	Kinematics Geometry of motion and practical mechanisms for generating motion form a	360
	unified subject in the kinematics of T & T'.  The background to dynamics  Little agreement existed in mid-century on the fundamental concepts and	372
	laws of dynamics, especially concerning the relation of statics to dynamics.  Revisionist dynamics – work, energy, and Newton's laws  Reading 'action' and 'reaction' as rates of doing work, T & T' reinterpreted	380
	Newton's 3rd law as conservation of energy and attempted to derive all of dynamics from it.  Extremum principles	390
	Energy-based, as opposed to force-based, dynamics obtained a rigorous foundation through the principle of least action and other extremum conditions.	370
12	The hydrodynamics of matter General relations of ether and matter	396 397
	By the early 1850s Thomson was seeking a unified theory of air—ether, or 'aer', which would allow a continuous transition between molecules of matter and ether and between waves of sound and light.	



	Contents	хi
	Magnetic rotations  The theory centred on the rotational character of magnetism and on the consequent probability that molecules consisted of electrical 'fluid' in rotational motion, or vortices.	402
	Engineering and economy  The vortices had a powerful practical foundation in James Thomson's vortex turbines and vortex pumps.	412
	Vortex atoms From 1867, drawing on Helmholtz's mathematical work and Tait's experimental demonstrations, Thomson turned his full powers to vortex atoms.	417
	Gravity	425
	The vortex atoms suggested a revival of Le Sage's kinetic theory of gravity.  Kinetic theory of gases	427
	The atoms seemed ideal for simple thermodynamic systems. Extrema and dissipation: the problem of stability  If vortex motion were quasi-stable it might meet simultaneously the requirements of atomic permanence and of universal dissipation of energy, but stability remained conjectural.	431
	Waves in the vortex ether and a restructured methodology  To deal with refractive dispersion of light, Thomson separated off the analysis of waves in the ether, as a 'molar' problem, from the effects of matter on the waves, a 'molecular' problem. This molar-molecular distinction marked the end of 'aer'.	438
13	Telegraph signals and light waves: Thomson versus Maxwell Submarine telegraph theory Thomson's 1854 telegraph theory already suggests why he would later reject Maxwell's electromagnetic theory of light.	445 446
	Measurements, units, and velocity Electrical measurements, interpreted on a fluid theory of electricity, suggested that telegraph signals in air lines propagated as longitudinal pressure waves travelling at a velocity near that of light.	454
	Longitudinal waves and light The practical success of his telegraph theory provided Thomson's ground, in his 1884 'Baltimore Lectures', for rejecting Maxwell's theory of light waves and for defending an elastic-solid theory.	458
	The methodology of 'look and see'  The lectures articulate a methodology which insists on direct sensory perception as the guarantor of validity of theoretical entities.	463
	Confrontation with Maxwell's ghost Following Hertz's experiments, widely thought to have demonstrated electromagnetic waves, Thomson launched a direct attack on Maxwell's theory.	471
	Ether, electricity, and ponderable matter By 1890 he had attained considerable success with an alternative theory of a	482



xii Contents

	rotationally elastic (magnetic) ether and a highly abstract electrical 'fluid'. Mephistopheles  The decadent forces of mathematical nihilism, in Thomson's view, ultimately won out over his own practical realism.	488
	III The economy of nature: the great storehouse of creation	
14	The irreversible cosmos The universal dissipation of energy Thomson's belief in the principle expressed a deep theological commitment. Sources of energy: the nature of the sun's heat In 1854 he concluded that neither primitive heat nor chemical action could supply the sun's energy. The gravitation theory of the sun's heat He adopted instead a theory of a gravitationally driven meteoric vortex, strikingly similar to James's vortex turbine. The origins of the sun and solar system Gravitation, in fact, might have been the origin of all motion and of all	497 497 502 508 518
	condensed bodies in the universe, and would ultimately bring the end of the solar system.	
15	The age of the sun controversies  On the age of the sun's heat  Switching by 1862 to a contraction theory of the sun's heat, Thomson estimated its age as probably less than 100 million years, severely constraining Darwin's theory of evolution.	524 526
	Thomson's cosmological vision  He now reiterated his view of universal progression from an ordered beginning in potential energy to a chaotic end in kinetic energy uniformly distributed, and thus uniformly hot.	533
	The progress of solar dynamics Thomson's developing theory of the sun's heat, grounded in an engineering view of its machinery, yielded a reduced age estimate of less than 20 million years.	538
	Lord Kelvin and the age of the sun Controversy in the 1890s and even the discovery of radioactivity did not dissuade the new peer from his earlier estimate of the age of the sun's heat.	544
16	The secular cooling of the earth William Hopkins and the doctrine of central heat The progressionist doctrine of terrestrial cooling involved a vigorous research programme in defence of the earth's solidity.	552 553
	Thomson, Helmholtz, and the importance of terrestrial temperatures  Thermal measurements in the earth's surface indicated a relatively short time period since the earth had been molten.	559



	Contents	xiii
	The secular cooling of earth In 1862 Thomson estimated the cooling period at between 20 and 400 million	561
	years  The rigidity of earth  On the basis of rotational phenomena he argued that the earth must be far more rigid than glass, and thus essentially solid and cooling by conduction.	573
17	The age of the earth controversies On geological and biological time Thomson's attack on uniformitarian geology, and his controversy with	579 580
	Huxley, heated up in the late 1860s.  On the harmony of geology and physics  Between 1870 and 1890 many geologists learned to live with Thomson's 100 million year age estimate, but rejected more radical reductions.	590
	The younger Darwin: a critique of tidal friction and secular cooling George Darwin offered telling critiques of the details of Thomson's theorizing, while agreeing with him in general.	597
	Lord Kelvin and the age of the earth: 1892-1907 As for the sun, the discovery of radioactivity did not alter Kelvin's view on the age of the earth.	602
18	The habitation of earth  Mind over matter  The 2nd law of thermodynamics highlighted the status of free will standing between laws and miracles.	612 612
	The demon Two factors, infinity and instability, removed the 2nd law, and physical dynamics generally, from the deterministic realm of abstract dynamics, allowing for the operation of mind on matter without violation of natural law.	621
	The origin and evolution of life on earth The strict distinction of mind from matter, which informed Thomson's view of free will, also lay behind his critique of Darwinian evolution.	633
	IV Energy, economy, and Empire: the relief of Man's estate	
19	The telegraphic art  On the harmony of theory and practice in engineering: principles of economy  The Glasgow Philosophical Society, in its membership and its programme, epitomized the mutual support of science and industry that accompanied the second industrial revolution.	649 652
	On the discord of theory and practice in telegraph engineering  The Atlantic telegraph project made scientific engineering an economic necessity.	661
	The making of Sir William Thomson	667



xiv Contents

He contributed essential instruments, precision measurements, testing, and theory to the success of the cable enterprise.

20	Measurement and marketing: the economics of electricity  Electrical units of measurement: the absolute system  The interests of industry and science merged in a system of measurement based on units of work.	684 684
	Partnerships and patents  Thomson and his partners prospered along with telegraphic industry through	698
	skilful marketing of patented instruments.  Power and light: the economics of electricity	712
	Through knighthood and peerage he stood as a leading spokesman for science-based industry.	712
21	Rule, Britannia: the art of navigation	723
	The shipyard of Empire	727
	In Glasgow, centre of modern iron shipbuilding for Britain and the world, Thomson would perfect his navigational instruments.	
	The Lalla Rookh	733
	Symbol of adventure, wealth, social advancement, and a new marriage, the schooner-yacht served from 1870 as a summer home and testing ground for instruments.	
	Sounding the deep sea	740
	Thomson quickly developed a prototype sounding machine using pianoforte wire.	, , ,
	The navigational sounding machine	748
	A commercial version found an appreciative audience.	
22	The magnetic compass	754
	Archibald Smith and the magnetism of ships	755
	From the 1840s Thomson had interacted with Smith concerning the	
	magnetism of iron ships and its effect on compasses.  The practical problems of compass correction	763
	Controversy and distrust surrounded the subject in the 1850s.	703
	Sir William Thomson's patent compass	770
	From 1871 Thomson worked out ideal theoretical conditions for a magnetic	
	compass and practical techniques for realizing them.  The commercial compass and sounding machine	776
	By 1880 his patented instruments had become the standard of the commercial	//0
	fleet of the Empire.	
	Sir William Thomson and the British Admiralty	786
	His conquest of the Queen's fighting ships required a more extended campaign.	
23	Baron Kelvin of Largs	799
•	The first 'scientific' peer	802



	Contents	xv
ar ' l L	Liberal Unionist politics, along with his contributions to knowledge, wealth, and power, raised Sir William to the peerage in 1892.  No time spent in idleness'  Literally until his death, Kelvin maintained his full activity as the Lord of British Science.	811
Bibli	ography	815
Index	r	838