The “Newtonian Synthesis”

- *The* Scientific Revolution:
- Copernicus, Kepler, Galileo, Newton
- Standard view:
- All built on Copernican theory of course; and Newton’s theory combined or synthesised Galileo’s laws and Kepler’s laws – and went way beyond them - and hence formed the culmination of the scientific revolution

The “Newtonian Synthesis”

- Galileo gave an account of terrestrial motion (which solved the Copernican problem of no apparent effect of the earth’s motion)
- Kepler gave an account of planetary motion which embodied Copernican theory, though as the same time significantly modified it
- Newton developed a theory that gives an account of *all* motion
- An account that yields Galileo’s laws and Kepler’s laws as particular ‘special’ cases.

The “Newtonian Synthesis”

- There is a good deal in this standard story that is broadly correct
- However the claim about Kepler’s and Galileo’s laws being special cases of Newton’s theory cannot be correct – as Duhem realised and Popper later reiterated.
- Duhem pointed out that far from Galileo’s and Kepler’s laws following from Newton’s theory, they are strictly logically *inconsistent* with it.
- Getting straight about the real logical relations invovled here sheds light on a number of issues in general philosophy of science; including:
- 1. Inter-theory reduction
- 2. “Explanation by correction”
- 3. How theory change can be “essentially cumulative” despite the strict inconsistency of the newer and older theories

KEPLER'S laws of planetary motion

- Kepler's laws
- 1. All planets move in elliptical (*not* circular) orbits around the sun which occupies one of the common foci of the ellipses.
- 2. Each planet moves in such a way that the radius arm connecting it to the sun sweeps out equal areas in equal times.
- 3. The periods T and mean radii R of *all* planetary orbits satisfy $T^2/R^3 = K$ for some single constant K

GALILEO's laws of terrestrial motion

1. Law of free fall: all freely falling bodies undergo constant acceleration (and therefore fall through the same height in the same time)
2. Laws of projectile motion: (basically) all projectiles move with a velocity that is the vector combination of their initial (and constant) horizontal velocity and of a vertical component changing under the influence of a constant downward acceleration.

GALILEO's laws of terrestrial motion

- 1. $a = dv/dt = d^2s/dt^2$
- So if a = g (= constant) i.e. independent of mass
- Then $v = \int g\ dt = gt$
- And $s = \int v\ dt = \int gt\ dt = ½\ gt^2$ for ANY body falling from r
- (of course difficult at Galileo's time to measure time elapsed and distance of fall accurately enough to precisely confirm this with regular falling bodies – hence his famous inclined plane experiments which showed that, to a very good approximation, distance covered is indeed proportional to time-squared)

GALILEO's laws of terrestrial motion

- 2. $\mathbf{v}_{total} = v_{horizontal} + v_{vertical}$
- So for example a cannonball launched at θ^0 to the horizontal at velocity **v** will satisfy
- **v** = $v\sin\theta$ [in the vertical direction] + $v\cos\theta$ [in the horizontal]
- Horizontal component $v\cos\theta$ remains constant (ignoring air resistance)
- Vertical component is affected by gravity
- Gravity generates a velocity after a time $t = gt$
- This is obviously downward
- So Galileo's law predicts, for example, that
- (a) whatever the angle of firing the trajectory of the ball will form a parabola
- (b) the maximum range will be achieved when the cannon is pointed at 45^0
- How this solves Copernicus's problem

NEWTON's theory

- ***Laws of motion:***

1. Every body continues in its state of rest or uniform motion in a straight line unless acted on by a net external force.
2. If the total force acting on a body of mass m at a particular time is **F**, then that body's acceleration at that time is **F**/m. (**F** = m**a**)

3. To every action there is an equal and opposite reaction.

- *Principle of Universal Gravitation:*

4. Any two bodies in the universe attract one another with a force equal to

$F_{grav} = (Gm_1 m_2)/ r^2$

where m_1 and m_2 are the masses of the two bodies, r is the distance between them (or more strictly between their centres of mass) and G is a universal constant.

The Newtonian ‘synthesis’

- Usual claim: Newton’s theory simply absorbs Kepler’s and Galileo’s laws – that is, the latter simply become special cases of the former.
- That is, Kepler’s Laws can be deductively derived from Newton’s theory by restricting that universal theory to the case of the motions just of planets.
- Similarly, Galileo’s Laws can be deductively derived from Newton’s theory by restricting that universal theory to the cases of bodies falling close to the earth’s surface, or to projectiles launched on the earth.

The Newtonian 'synthesis'

- Ernest Nagel *The Structure of Science:*
- "Galileo's *Two New Sciences* was a contribution to the physics of free-falling terrestrial bodies, a discipline which in his day was considered to be distinct from the science of celestial motions. Galileo's laws were eventually absorbed into Newtonian mechanics and gravitational theory, which was formulated to cover both terrestrial and celestial motions.
- The reduction of the laws of terrestrial and celestial motions to a single set of theoretical principles has for its outcome simply the incorporation of two qualitatively similar phenomena into a more inclusive class…."
- And he says similar things about Kepler
- The Newton/Galileo case is indeed Nagel's chief example of a 'homogenous reduction'
- (One theory T 'reducing'to another theory T' just when T' entails T (modulo initial conditions)

The Newtonian ‘synthesis’

- Indeed, the claim is often made that Newton’s theory can be ‘induced’ from the laws of Galileo and Kepler –
- both claims assume a straightforward cumulative, non-modificatory development.
- Finally, Newton himself quite categorically claimed to have *deduced* his principle of universal gravitation from Kepler’s laws.
- Although these 3 claims are logically distinct they all seem clearly to presuppose a continuity between Kepler’s and Galileo’s laws, on the one hand, and Newton’s theory on the other.
- Yet first Duhem, and then Popper, pointed out that the laws and the theory are inconsistent (and of course Newton knew this himself).

Newton and Kepler

- *Case of the First law*
- So what's going on? Let's concentrate just on Nagel's claim and look first at Newton and Kepler
- K says any planet moves on an ellipse around a sun assumed fixed
- N says that any planet *would* move on an ellipse (*either* related to the sun *or* indeed to the common centre of motion of the sun and the planet) IF the only two bodies in the universe were the sun and that single planet
- But in fact of course there are the other planets and they exert a gravitational attraction too
- Any particular planet therefore moves, according to N's theory, on a 'perturbed' ellipse, the perturbations being especially noticeable empirically when the planet is in conjunction with one of its near neighbours.

Newton and Kepler

- N's theory does *not* then entail K's first law, it entails the negation of it.
- However, because the sun is overwhelmingly the most massive body in the solar system, N's theory 'entails K's first law as a first approximation'
- General point: N explains K's law's empirical success while entailing that the law itself is false.

Newton and Kepler

- *Case of third law:*
- K's 3rd law says
- For any two planets, the orbital periods T_1 and T_2 and the average distances of the planets from the sun, R_1 and R_2 are related by $(T_1/T_2)^2 = (R_1/R_2)^3$ – *this entails that R^3/T^2 is a constant for any planet.*

Newton and Kepler

- According to Popper, Newton's theory entails (in a series of one planet 'models') that
- For each planet of mass m_p, the value for that planet of R^3/T^2 is $m_p + m_s$ where m_S is the mass of the sun.
- Hence again N's theory entails that Kepler's third law is strictly false – it would be true only if every planet had the same mass (and this was known to be false).
- Notice, however, that we again have 'entailment as a first approximation' – N's theory explains why Kepler's law had seemed to be empirically successful: even though false it was 'close to the truth'.
- This is again because m_p for any planet p is small compared to m_s and so m_p+m_s is 'almost constant'

Newton and Galileo

- G's law says that freely falling bodies fall with constant acceleration (and this is also the basis for his law of projectile motion)
- N's theory says (and even this is itself an approximation)
- A falling body falls essentially in a way determined by the gravitational interaction between it and the earth.

Newton and Galileo

- 1. That is (principle of universal gravitation) the force acting on the body of mass m during its fall is given by
- $F_{grav} = (G\, m m_e)/ r^2$
- where m_e is the mass of the earth and r is the distance between the centre of mass of the falling body and the centre of mass of the earth.
- 2. Hence the falling body has an acceleration at any instant given by dividing this force by its mass (Second law) – so
- $a_{grav} = (G m_e)/ r^2$
- Notice that *r is not a constant but constantly changes as the ball falls* – in fact because r decreases, a_{grav} constantly increases

Newton and Galileo

- HOWEVER, again we have explanation of the empirical success of Galileo's law alongside entailment of its negation.
- This is best seen by re-expressing the distance of the ball from the centre of the earth as r + R, where R is the radius of the earth, and r the elevation of the ball at a given instant above the earth's surface
- $a_{grav} = (Gm_e)/ (r + R)^2 \approx a_{grav} = (Gm_e)/ R^2$ (for any achieved r)
- So again we have explanation of the empirical success of Galileo's law alongside entailment of its negation –
- although false G's law is 'close to the truth' (assuming Newton's theory to be true).

Philosophical Lessons

- 1. Nagel's claim that this is a straightforward case of 'homogeneous reduction' again cannot be literally true. Newton's theory far from entailing the laws of Kepler and of Galileo entails that those laws are false.
- 2. The claim that Newton's theory was 'induced' or the claim (actually made by Newton himself) that that theory was deduced from the 'phenomena' supplied by Kepler and Galileo also cannot be literally true.
- 3. The straightforward accumulative view of the development of science that was presupposed by the logical positivists fails to work even in straightforward, 'non-revolutionary' cases.
- 4.Nonetheless, it would be a mistake to underestimate the importance of the accumulation that does occur in this case – but it is 'accumulation with correction'. Although Newton's theory does not explain Kepler's and Galileo's laws (on the H-D model) it does 'explain their empirical success'.