Chapter 1

The extraction of gravitational potential energy from material which accretes on to a gravitating body is now known to be the principal source of power in several types of close binary systems,and is widely believed to provide the power supply in active galactic nuclei and quasars

For the *most luminous objects in the Universe* (X-ray binaries, quasars, AGN), **nuclear fusion is insufficient**. Their luminosities exceed what stellar nuclear processes can supply.

Accretion as the key mechanism:

When matter falls (accretes) onto a **compact object** (white dwarf, neutron star, black hole), its **gravitational potential energy** is converted into heat and radiation.

Observational confirmation:

Advances across the electromagnetic spectrum (radio → γ-rays) revealed high-energy emissions that are natural signatures of accretion.

Discoveries of **pulsars** confirmed neutron stars, and black holes gained strong theoretical and observational support.'

For white dwarfs with M ~ M, R∗ ~ 109 cm,nuclear burning is more efficient than accretion by factors 25–50. However,it would be wrong to conclude that accretion on to white dwarfs is of no great importance for observations,since the argument takes no account of the timescale over which the nuclear and accretion processes act. In fact, when nuclear burning does occur on the surface of a white dwarf,it is likely that the reaction tends to 'run away' to produce an event of great brightness but short duration, a nova outburst,in which the available nuclear fuel is very rapidly exhausted. For almost all of its lifetime no nuclear burning occurs,and the white dwarf (may) derive its entire luminosity from accretion.Binary systems in which a white dwarf accretes from a close companion star are known as cataclysmic variables and are quite common in the Galaxy.

For accretion on to a 'normal',less compact,star,such as the Sun,the accretion yield is smaller than the potential nuclear yield by a factor of several thousand. Even so,accretion on to such stars may be of observational importance. For example,a binary system containing an accreting main-sequence star has been proposed as a model for the so-called symbiotic stars.

For a fixed value of the compactness, M/R∗,the luminosity of an accreting system depends on the rate $\dot{M}$ at which matter is accreted. At high luminosities,the accretion rate may itself be controlled by the outward momentum transferred from the radiation to the accreting material by scattering and absorption. Under certain circumstances, this can lead to the existence of a maximum luminosity for a given mass,usually referred to as the Eddington luminosity

Eddington limit

Consider a steady spherically symmetrical accretion, assuming the accreting material to be mainly hydrogen and to be fully ionized. Under these circumstances, the radiation exerts a force mainly on the free electrons through Thomson scattering. If S is the radiant energy flux (erg

$s^{-1}cm^{-2}$) and $\sigma_T = 6.7 \times 10^{-25}$ cm^2 is the Thomson crosssection,then the outward radial force on each electron equals the rate at which it absorbs momentum, $\sigma_T S/c$. Due to the electrostatic force between the electrons and protons, while the electrons are pushed outwards the drag the protons with them.
the net inward force on an electron–proton pair is

$$\left(GMm_{\mathrm{p}} - \frac{L\sigma_{\mathrm{T}}}{4\pi c}\right)\frac{1}{r^2}.$$

And the limiting luminosity for which this force vanishes is the Eddington limit
At luminosities greater than this the outward pressure of radiation would overpower the inward gavitational attraction and therefore the accretion process would stop. If all the luminosity comes from accretion then the source would switch off and if there were some other means like nuclear burning then this would result in the blowing off of the outer layer of gases and the source would become unsteady
A slight extension can be made here without difficulty: if the accretion occurs only over a fraction f of the surface of a star,but is otherwise dependent only on radial distance r,the corresponding limit on the accretion luminosity is fL(Edd)
Almost complete ionization is likely to be justified however in the very common case where the accreting object produces much of its luminosity in the form of X-rays due to the fact that their emission results in the ionization of the gases present
certain types of system show a tendency to behave as 'standard candles' in the sense that their typical luminosities are close to their Eddington limits thereby showing relatively the same brightness and intensity which are useful for distance calculation and other calculations.
The case of black holes are different since in black holes there is no solid surface and the incoming matter may also enter the blackhole thereby only increasing the mass, this results inn the fact that all the Kinetic energy of the incoming matter may not be converted to radiation, The incoming matter has some angular momentum, this results in a formation of an accretion disk around the black hole before the event horizon, eventually as the gas spirals inwards the gravitational potential energy becomes thermal energy and radiation is emmitted.
To take this into account we had a dimentionless quantity η, efficiency to the luminosity formula and therefore $L_{acc} = 2\eta GMM/R$,
Accretion is considered as the ultimate source of energy for the nuclei of active galaxies and quasars due to the large luminosities involved that cannot be done by other means like nuclear burning
AGN luminosity demands enormous masses thereby ruling out white dwarfs and neutron stars thus, only massive black holes are plausible candidates for accreting objects in active galactic nuclei
Optically thick accretion
Photons interact multiple times before escaping which results in thermal equilibrium between radiation and matter and $T_{rad} \sim T_b$
Optically Thin accretion
Photons barely have any interactions and therefore $T_{rad} \sim T_{th}$

These only apply when particles have a Maxwellian distribution of velocity and are therefore dependent on a singular temperature

Provided we are interested only in lengthscales L λ we can regard the gas as a continuous fluid,having velocity v,temperature T and density ρ defined at each point. We then study the behaviour of these and other fluid variables as functions of position and time by imposing the laws of conservation of mass,momentum and energy

The fundamental equations governing the flow are conservation of mass (the continuity equation), momentum (the Euler equation), and energy. These equations are supplemented by an equation of state, typically the ideal gas law, which is appropriate for most astrophysical gases outside degenerate objects. External forces, most importantly gravity, appear explicitly in the momentum equation, while radiative losses and thermal conduction enter through the energy equation. In many astrophysical situations, viscosity and heat conduction can be neglected to first approximation, significantly simplifying the analysis.

Special attention is given to steady flows, where time derivatives vanish. Two limiting thermodynamic cases are particularly important: adiabatic flows, where no heat is exchanged and entropy is conserved, and isothermal flows, where the temperature is kept constant by efficient radiative processes. These assumptions lead to simple polytropic relations between pressure and density, which are widely used in accretion theory.

sound waves, which arise from small perturbations about hydrostatic equilibrium. These propagate at the sound speed, a quantity determined by the local temperature and equation of state. The sound speed plays a crucial role in accretion physics, as it determines how rapidly pressure information can travel through the gas. The distinction between subsonic and supersonic flow becomes fundamental: subsonic flows adjust smoothly to pressure gradients, while supersonic flows are effectively pressure-blind and prone to shocks.

The key geometrical concept introduced is the Roche potential, which describes the combined gravitational and centrifugal effects in a rotating binary frame. Each star is surrounded by a Roche lobe, and when the donor star fills its Roche lobe, matter can flow through the inner Lagrange point toward the compact object. This process, known as Roche lobe overflow, is the dominant mass-transfer mechanism in many accreting binaries.

The evolution of the binary is tightly coupled to mass transfer. Depending on the mass ratio of the donor and accretor, mass transfer can be stable or unstable. If the donor is less massive than the accretor, mass transfer tends to be stable and proceeds on nuclear or angular-momentum-loss timescales. If the donor is more massive, the orbit shrinks, driving runaway mass transfer that often leads to a common-envelope phase or merger. These considerations explain why some classes of binaries are long-lived, while others are short-lived and rarely observed.

Because transferred matter carries significant angular momentum, it generally cannot fall directly onto the accretor. Instead, it circularizes and forms an accretion disc. The formation of a disc is shown to be a generic outcome of Roche lobe overflow, since the circularization radius is far larger than the radius of compact accretors such as white dwarfs, neutron stars, or black holes.

Accretion refers to the release of gravitational energy when matter falls into a compact object's potential well, and it is one of the most efficient energy-generation mechanisms in astrophysics. When matter accretes onto white dwarfs, neutron stars, or black holes, a significant fraction of the gravitational binding energy is converted into radiation. Accretion luminosity is limited by radiation pressure, leading to the Eddington limit, which sets a maximum steady luminosity and corresponding mass accretion rate for a given compact object. This provides a direct link between observed luminosities and accretor masses, implying that the brightest quasars must host supermassive black holes. Because infalling matter carries angular momentum, direct radial accretion is generally impossible. Instead, matter forms an accretion disc and spirals inward as angular momentum is transported outward. Molecular viscosity is far too weak to account for the required transport, so an effective viscosity is needed. The thin accretion disc model provides a successful description of many observed systems. Such discs are geometrically thin, nearly Keplerian, and able to cool efficiently. Their predicted temperature and dissipation profiles depend primarily on gravity and the accretion rate rather than on the detailed form of viscosity, a result that is strongly supported by observations. Thin discs explain the dominant emission components of X-ray binaries, cataclysmic variables, and quasars.
Time variability in accreting systems arises from disc instabilities. The hydrogen ionization (thermal–viscous) instability causes discs to cycle between cool, low-luminosity states and hot, high-luminosity states. This framework explains dwarf novae and soft X-ray transients. In X-ray binaries, irradiation from the central source stabilizes large parts of the disc, producing longer, brighter, and rarer outbursts compared to white-dwarf systems.On galactic scales, the same accretion physics governs active galactic nuclei. Galaxy mergers drive gas toward central black holes, triggering rapid often super Eddington accretion, strong outflows, and jets. These outflows couple the growth of the black hole to the host galaxy, regulating star formation and naturally producing the observed black-hole–bulge mass (M–σ) relation. Accretion therefore links small-scale disc physics to the large-scale evolution of galaxies and cosmic structure.