Frank, King and Raine

Summary (chapter- 1, 2, 4)

Accretion has emerged as one of the most important energy-generation mechanisms in modern astrophysics. While early physicists believed gravity to be inadequate as a long-term power source for stars like the Sun, present-day astronomy relies heavily on gravitational energy to explain the most luminous objects in the Universe. In many extreme systems, such as X-ray binaries, quasars, and active galactic nuclei, nuclear reactions alone are insufficient to account for the observed luminosities. Instead, the release of gravitational potential energy as matter falls onto compact objects provides a far more efficient and powerful energy source.

When matter accretes onto a gravitating body of mass M and radius R^*, the gravitational energy released per unit mass is proportional to GM/R^*. This means that the more compact the object, the greater the energy yield. For neutron stars, accretion releases about 10^20 erg/g, which is roughly twenty times larger than the energy released by nuclear fusion of hydrogen into helium. Black holes, being even more compact, can in principle convert an even larger fraction of rest mass into energy, although not all of this energy necessarily escapes as radiation. White dwarfs are less efficient accretors than neutron stars, but accretion remains observationally important for them because nuclear burning on their surfaces is intermittent, whereas accretion can provide a steady luminosity over long periods.

At high luminosities, accretion is limited by the interaction between radiation and infalling matter. Radiation exerts an outward force on electrons through Thomson scattering, and because electrons and protons are coupled by electrostatic forces, radiation pressure can counteract gravity. Balancing these effects leads to the Eddington limit, which defines the maximum steady luminosity an accreting object of a given mass can sustain. If this limit is exceeded, accretion is halted or matter is expelled from the system. The Eddington limit therefore places an upper bound on both luminosity and accretion rate and plays a central role in understanding the behaviour of accreting stars and black holes. In particular, the enormous luminosities of quasars imply accretion onto supermassive black holes with masses exceeding about 10^9 $M\odot$.

The radiation emitted by accreting systems spans a wide range of the electromagnetic spectrum. The characteristic photon energies depend on whether the accreting flow is optically thick or thin. If the flow is optically thick, the radiation thermalizes and emerges with a blackbody spectrum, while optically thin flows can emit high-energy radiation directly. Accretion onto neutron stars and stellar-mass black holes typically produces X-rays and even gamma rays, whereas accreting white dwarfs emit mainly in the optical, ultraviolet, and soft X-ray bands. These predictions are well supported by observations of X-ray binaries and cataclysmic variable stars.

To understand how accretion actually proceeds, one must consider the gas dynamics of the infalling matter. Accreting material behaves as a fluid governed by conservation of mass, momentum, and energy. A particularly important concept is the sound speed, which determines how rapidly pressure disturbances propagate through the gas. Whether the flow is subsonic or supersonic strongly affects its behaviour. In spherical accretion, first analysed by Bondi, there exists a unique physical solution in which the flow passes smoothly from subsonic to supersonic at a critical radius known as the sonic point. The accretion rate in this case is determined by the density and temperature of the gas far from the star. However, for typical interstellar conditions, spherical accretion rates are extremely small and produce luminosities too low to be easily observed.

Much more efficient accretion occurs in binary systems. In close binaries, mass transfer can take place when one star fills its Roche lobe, allowing matter to flow through the inner Lagrange point toward its companion. This process, known as Roche lobe overflow, is highly effective and is responsible for most luminous accreting binaries. The transferred material usually possesses significant angular momentum, which prevents it from falling directly onto the accreting star. Instead, it settles into orbit and forms an accretion disc.

Accretion discs are central to the physics of binary accretion. Within the disc, matter moves on nearly circular Keplerian orbits and gradually spirals inward as it loses angular momentum. As material moves deeper into the gravitational potential well, gravitational energy is converted into heat and ultimately radiated away. Roughly half of the total accretion luminosity is emitted by the disc itself, with the remaining energy released very close to the surface of the compact object or, in the case of black holes, near the event horizon. Accretion discs therefore act as highly efficient engines for extracting gravitational energy.

A key unsolved problem in accretion theory is the mechanism responsible for transporting angular momentum outward through the disc. Molecular viscosity is far too weak to account for observed accretion rates, implying the existence of an effective, turbulent viscosity. This uncertainty is commonly encapsulated in the phenomenological α-prescription, which expresses the viscosity in terms of local disc properties. Although this approach has been very successful in modelling discs, it does not explain the physical origin of the turbulence.

Recent advances suggest that magnetohydrodynamic turbulence, driven by the magnetorotational instability, is the most promising mechanism for angular momentum transport in accretion discs. Even weak magnetic fields can destabilize differentially rotating flows, leading to turbulence that naturally transports angular momentum outward and allows accretion to proceed. Numerical simulations support this picture and yield values of the effective viscosity consistent with observations.

Not all accretion in binaries occurs via Roche lobe overflow. In systems containing massive, early-type stars, accretion can occur from a stellar wind. Although this process is relatively inefficient, the high mass-loss rates of massive stars can still power bright X-ray sources. Disc formation in wind-fed systems is uncertain and depends sensitively on the wind velocity and binary geometry. Other mechanisms, such as irradiation-driven mass transfer, are generally ineffective except in special cases like supersoft X-ray sources.