Abstract

Clusters of galaxies are the largest observed objects in the sky which are gravitationally bound, and the brightest X-ray emitters. Observed X-ray spectra of clusters of galaxies consist of continuum emission components and lines of highly ionized heavy elements from a thin hot plasma in collisional ionization equilibrium (CIE). The existence of lines revealed that the intracluster medium (ICM) is a mixture of metal-poor primordial gas and metal-rich processed gas. The distributions of heavy elements from line analysis is a clue to investigate the chemical evolution of galaxy clusters. There are such schemes as which heavy elements are ejected into the interstellar space through supernova or stellar mass loss and injected into the intra-cluster space through ram-pressure stripping or galactic winds.

The ICM has a small optical depth, that is, optically thin for continuum because the Thomson scattering optical depth $\tau_{\rm Th}$ is much less than unity, typically 10^{-2}. However this is not the case for the stronger resonance lines. A resonance-line photon is scattered by the ions in the same state of ionization as an ion emitting the photon, and has relatively large absorption oscillator strength (e.q. $f_{12} > 0.1$). Then, it is re-emitted, generally in a different direction. Therefore, the optical depth of the resonance lines is hundreds or thousands times larger than the $\tau_{\rm Th}$.

The resonance lines are scattered mainly in the center of a cluster where the density is high, and are observed to be suppressed. The diffusion of the photons with respect to frequency tends to form the saddle-shaped line profiles. On the other hand, the suppressed component is observed to be a significant enhancement in outer part of cluster. Eventually the total intensity over the whole cluster is not changed.

149 clusters of galaxies, Virgo Cluster and Perseus Cluster and so on were observed with *ASCA* satellite, which is capable for imaging spectroscopy. From the spectra integrated over annual rings whose center is located at the cluster center, temperatures are confirmed to be lower at the center of many nearby clusters (redshift < 0.1) with factor < 2, for example, A496 and Perseus cluster. On the other hand, some of distant clusters (redshift > 0.1) are suggested to have radial temperature decline with factor less than 2, for example, A2204 and A1689. Based on the line features, especially iron $\rm K_\alpha$ line, abundances are enhanced at the center of A496, A3158, M87 and Perseus cluster and so on.

Among the observed lines, iron $\rm K_\beta$ lines are found separately from $\rm K_\alpha$ lines by the GIS detectors, and He-like and H-like iron $\rm K_\alpha$ lines can be distinguished by at SIS detector. I called them $\rm K_\beta$-Blend, $\rm K_\alpha$-Blend, He-$\rm K_\alpha$-Blend and H-$\rm K_\alpha$-Blend. However $\rm K_\beta$-Blend

includes Ni K_α lines. I estimated the intensities and the ratios (K_α-Blend / K_β-Blend $\equiv R_1$, He-K_α-Blend / H-K_α-Blend $\equiv R_2$) of these lines. According to the results of GIS analysis, 80 % of clusters suggest that R_1 of cluster center tends to be smaller than that expected from optically thin plasma model and to increase as the radius. The results of SIS analysis show that R_2 of each cool clusters ($kT < 6$ ke$V$) is smaller than the model value. Furthermore, in order to get the sufficient photon statistics, 83 bright clusters of galaxies are divided into 4 groups with respect to temperature (1–3 ke$V$, 3–6 ke$V$, 6–9 ke$V$, > 9 ke$V$), all spectra of each groups are summed up, after the correction of the redshift. These spectra make it clear that these trends of ratios, R_1 and R_2, are univeral for clusters of galaxies. These results are consistent with the effect of resonance scattering.

On the other hand, He-K_β-Blend and H-K_β-Blend are separated in the statistical line analysis of SIS spectra. As the three new ratios (He-K_β-Blend / H-K_β-Blend $\equiv R_3$, He-K_α-Blend / He-K_β-Blend $\equiv R_4$ and H-K_α-Blend / H-K_β-Blend $\equiv R_5$) were also obtained, the line analysis could be done in detail.

In order to understand these observed ratios, I simulated 41 lines (He-K_α-Blend and H-K_α-Blend include 7 and 16 lines, and K_β-Blend consists of 18 lines.) in energy range between 6.4–8.2 ke$V$ in consideration of the effect of the resonance scattering, using Monte Carlo method. Then, I got the line intensity ratios R_1 and R_2, and compared them with observed line intensity ratios.

As a consequence, observed R_1 and R_2 of hot clusters ($kT > 6$ ke$V$) can be explained by the resonance scattering. The obtained τ of He-like iron K_α line of cluster center is 2–4. This indicates abundances estimated from K_α lines without considering the resonance scattering is factor ~ 2 smaller than real values at the cluster center.

Observed R_1 and R_2 of the cool cluster ($kT < 3$ ke$V$) are smaller than the values obtained by simulation of the resonance scattering, though the trend is consistent with the effect of the resonance scattering. Moreover the R_1 estimated from spectrum of the whole cluster is also smaller than the model ratio. It is needed to consider other causes, for example, some more characteristics of cluster such as size or to reform the atomic data. Especially, as one of them, the contamination fo Nickel K_α lines for cool cluster are considered. The R_3, R_4 and R_5 ratios suggest the existence of hot plasma or contamination of Kγ and Kδ.