Experimental plans with Tokyo-EBIT

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Abstract
A new electron beam ion trap (Tokyo-EBIT) has been completed in Institute for Laser Science, University of Electro-Communications, Tokyo. The maximum parameters of the electron beam are designed to be 340 keV and 300 mA. The preliminary experiments have been performed in 1997. We report here the recent results and planned experiments such as electron-ion collision experiments, atomic structure measurements by X-ray and visible spectroscopy and ion-surface interaction experiments.

§1. Introduction

The electron beam ion trap (EBIT) is a unique ion source which has been developed as a means of producing and trapping highly charged ions (HCIs) [1]. This device is based on the electron beam ion source (EBIS) concept [2], but with a shorter trap length to limit plasma instabilities [3]. We have recently constructed a new EBIT in the University of Electro-Communications, Tokyo, to study the physics of highly charged ions [4,5].

In this report, we introduce briefly the general feature of the Tokyo-EBIT, the recent results in preliminary experiments and the some research subjects planned.

§2. Overview of the Tokyo-EBIT

The Tokyo-EBIT is shown schematically in figure 1. An electron beam emitted from an electron gun is accelerated, magnetically compressed and injected in a drift tube assembly. This assembly consists of the successive three cylindrical electrodes. In the central drift tube HCIs are produced by successive ionization by electron impact. The HCIs are also trapped, radially by the space charge potential produced by the electron beam, and axially by the positive potential applied to the end drift tubes to the central one. After passing through the drift tube region, the electron beam is collected by an electron collector at the decelerated energy. The maximum electron beam energy is designed to be 340 keV. To achieve this condition, the gun and the collector are floated to -300 kV, and the drift tube (trap) assembly is to +40 kV. Compression of the electron beam is made by the combination of electrostatic and magnetic field applied in the region between the gun and the trap. The magnetic field is produced by a superconducting coil of Helmholz type. Eight observation ports are situated around the trap in the center of the Helmholz coil to facilitate spectroscopy, gas and probe injections.

Table 1 summarizes designed and presently achieved parameters of Tokyo-EBIT. The maximum energy is limited by the insulation voltage outside of the EBIT in air. We will use SF_6 gas at 2 atmospheres as the insulation gas when we will operate over 100 kV. The electron current of 250 mA has been achieved. This is not limited by the emissivity of the cathode itself, but by the stability of the electron beam at low energies (<100 keV). This value will be increased by increases of the electron beam energy. The magnetic field of 4.5 T has been already achieved.

§3. On-going experiments (1997).

Figure 2 shows a typical X-ray spectrum observed with a Ge solid state detector. The electron energy and the current in this measurement were 75 keV and 150 mA, respectively. We can see several peaks from three dominant species of ions: krypton, barium and tungsten. Krypton gas was injected from outside of the EBIT through the gas-injection port, while barium and tungsten were evaporated from the cathode and ionized in the trap region. Radiative recombination (RR) lines to the n=1, n=2 and n=3 levels of barium and krypton ions are observed. From the identification of these peaks, we can confirm that H-like and bare krypton and barium ions have been produced in the trap. The small peaks observed at 83 and 94 keV are from RR into the highly charged tungsten ions.

A two dimensional X-ray spectrum obtained by use of multiparameter data acquisition system [6] is shown in figure 3. Krypton gas was also introduced in this case. The electron beam energy to produce initial charge state distribution was 17 keV, which is almost identical to the ionization energy of He-like krypton ions (16.8 keV) and is much larger than that of Li-like krypton ions (4 keV). Therefore, He-like krypton ions are considered to be predominant in the trap. X-ray signal are measured by the Ge detector while the electron beam energy are changed linearly from 17 keV to 7 keV and then from 7 keV to 17 keV. This scan was performed once per 100 ms and its width was 20 ms. In this figure the horizontal axis represents the X-ray energy and the vertical axis the electron beam energy. X-ray signals along a vertical line at around 13 keV of X-ray energy is due to X-ray emission from n=2-1 transitions and that at around 15 keV is from n=3-1 transitions. Diagonal lines are attributed to RR processes, since the X-ray energy of RR processes increases linearly with the electron energy. At the crossing of the vertical and diagonal lines, there are strong peaks. These are resonance processes due to dielectronic recombination (DR) of He-like krypton ions. Since cross sections of RR processes can be estimated theoretically, the resonance strengths for DR processes might be determined by normalization of the line intensity of DR to RR.

Two kinds of X-ray spectra measured with a flat LiF(200) crystal spectrometer are shown in figure 4. A position sensitive proportional counter was used as a detector. We observed n=3-2 transitions in Ne-like barium and xenon ions. A 7.8 keV, 110 mA electron beam was used for each spectrum. At atomic number Z around Z=55, with increase of Z, suitable representation of Ne-like atomic systems changes from L-S coupling scheme to j-j coupling. As shown by Kagawa *et al* [7], the order of level energies and the oscillator strengths for the respective transitions between these levels oscillate at around Z=55 due to mixing of the wave functions. Accordingly, systematic measurements of wavelengths and intensity ratios for these transitions are important to check the theoretical treatment of relativistic many body systems.

Typical charge spectra of extracted argon and krypton ions are shown in figure 5. Both spectra were observed by pulsed mode in which the potential of the central drift tube is set to the same potential as the upper drift tube to dump the trapped ions. The charge state distribution measured using pulsed mode reflects the charge balance in the trap. For argon ions, when a 27.6 keV, 115 mA electron beam was used, bare argon ions show the maximum peak in the spectrum. For krypton, with a 48.2 keV, 130 mA electron beam, B-like ions (31+) show the maximum. The number of the extracted ions is typically several thousand counts per pulse in pulsed mode, and about 10^4 counts per second in continuous mode.

§4. Planned experiments.

As already mentioned, the present value of the maximum electron beam energy is limited by the insulation voltage of the system in air. The insulation system with use of SF_6 gas has been completed recently and will make it possible to increase the beam energy. We will begin 300 keV operation in near future.

We are planning to perform electron-ion collision experiments. We will measure electron impact ionization cross section of H-like and He-like ions by observations of extracted ions, in addition to X-ray spectroscopic studies. DR experiments will be systematically performed not only by X-ray measurement, but also by ion extraction methods.

As for high resolution X-ray spectroscopy, the measurement of transition energies in Ne-like ions will be systematically continued for HCIs with atomic numbers around 55. In addition, we are planning to develop a high energy spectrometer of transmission type to study a few electrons very high Z ions.

We intend to observe transitions in visible region. We are measuring the spectra for magnetic dipole transitions of $(3d^4)\ ^5D_3$-$^5D_2$ for Ti-like ions of Z=54-92. We have calculated wavelengths of these transitions, which are shown in figure 6. These wavelengths are obtained by the multi-configuration Dirac-Fock calculation (GRASP92 code) [8]. The wavelengths are anomalously stable with respect to Z. The measurements of wavelengths of these transitions give useful information for plasma diagnostics.

We are constructing an echelle type visible spectrometer with large spectral range and high resolution. This might be very useful to survey unknown spectra such as transitions between fine structure levels or hyper fine structure levels. By laser induced fluorescence spectroscopy, we will make precise spectroscopic studies in visible region. We have prepared OPO laser system which is tunable in the whole visible range. An optical system for introduction of the laser into the trap region is under consideration.

With an improved extraction line system for HCIs, we are planning to perform various kinds of ion-surface collision experiments.

References

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Figure captions

Figure 1. Schematic view of the Tokyo-EBIT

Figure 2. A typical X-ray spectrum taken with a Ge solid state detector.

Figure 3. A two dimensional X-ray spectrum for Kr ions.

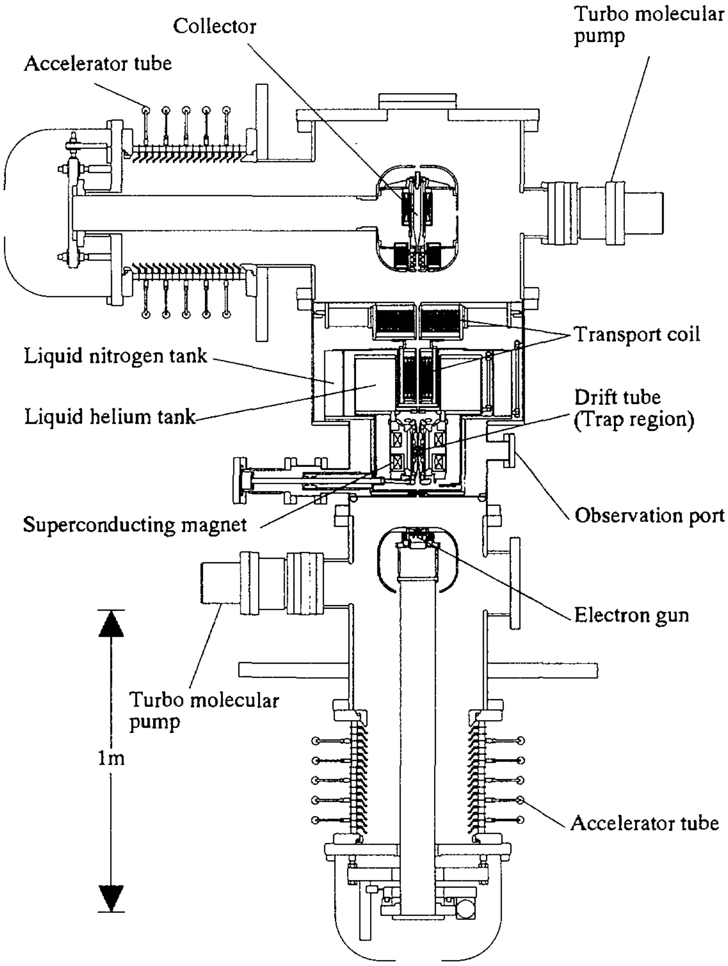
Figure 4. X-ray spectra of n=3-2 transitions in Ne-like barium and xenon ions taken with a flat LiF(200) crystal spectrometer.

Figure 5. Charge spectra of extracted argon and krypton ions.

Figure 6. Wavelengths of magnetic dipole transition of $(3d^4)$ $^5D_3$-$^5D_2$ for Ti-like ions. These are obtained by the multi-configuration Dirac-Fock calculation by use of GRASP92 code.

Table 1 The operational parameters of the Tokyo EBIT.

Parameter	Tokyo-EBIT (designed)	Tokyo-EBIT (achieved)
Beam Energy (keV)	10-340 (in SF_6)	2.5-80 (in air)
Beam Current (mA)	0-300	0-250
Magnetic field (T)	0-4.5	0-4.5


Collector
Turbo molecular pump
Accelerator tube
Transport coil
Liquid nitrogen tank
Liquid helium tank
Drift tube (Trap region)
Observation port
Superconducting magnet
Electron gun
Turbo molecular pump
1m
Accelerator tube

Fiugre 1

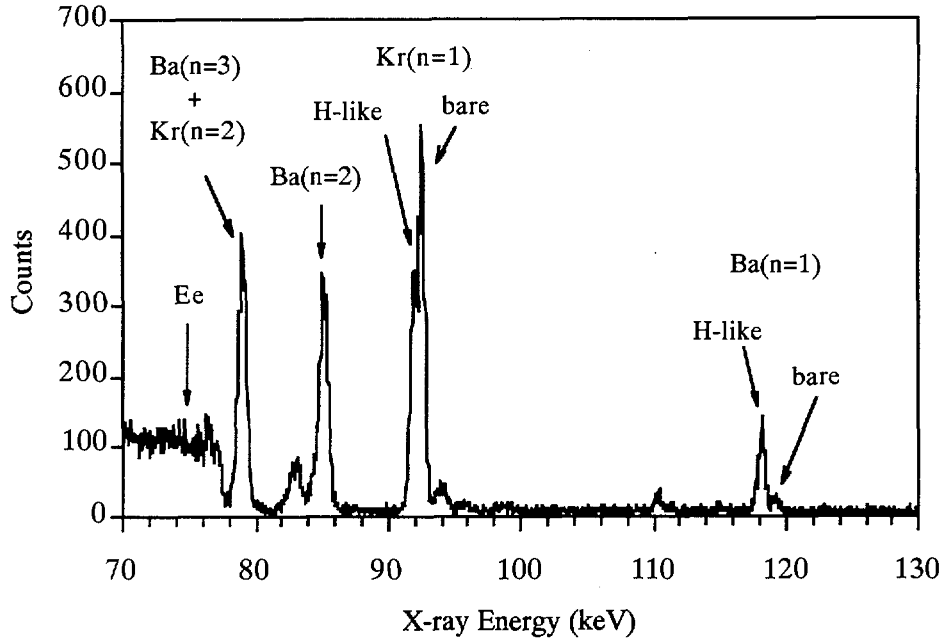


Figure 2

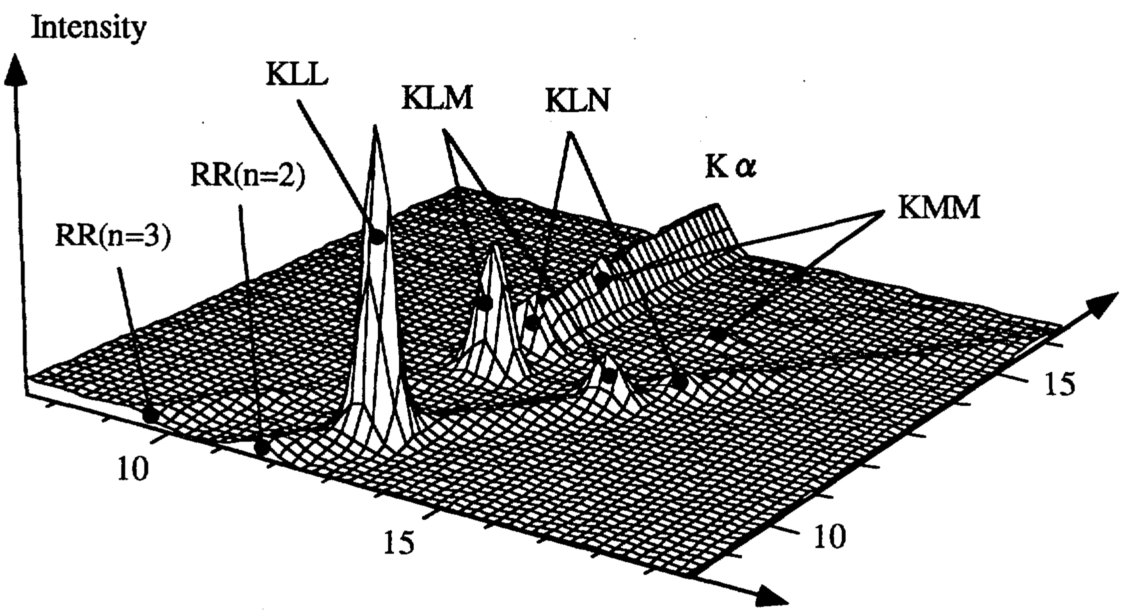
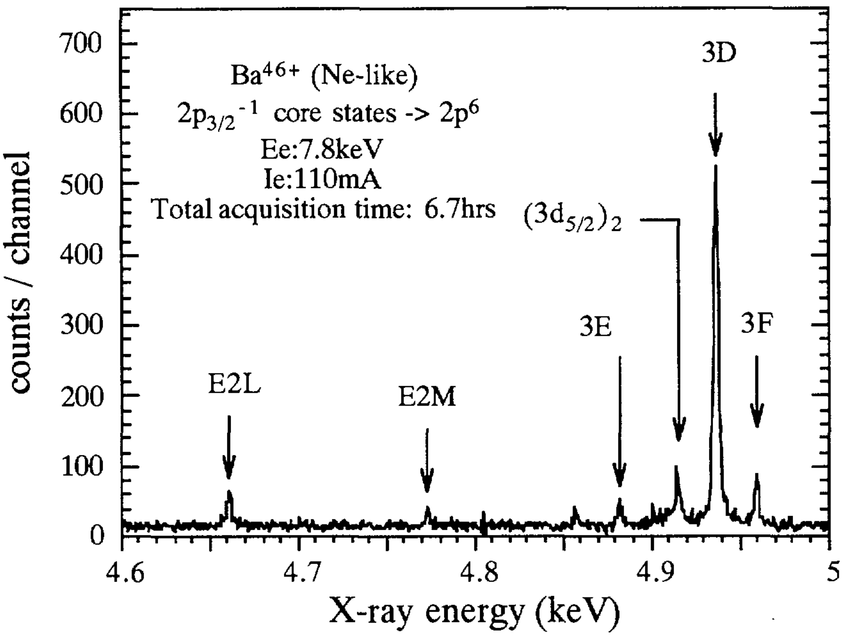
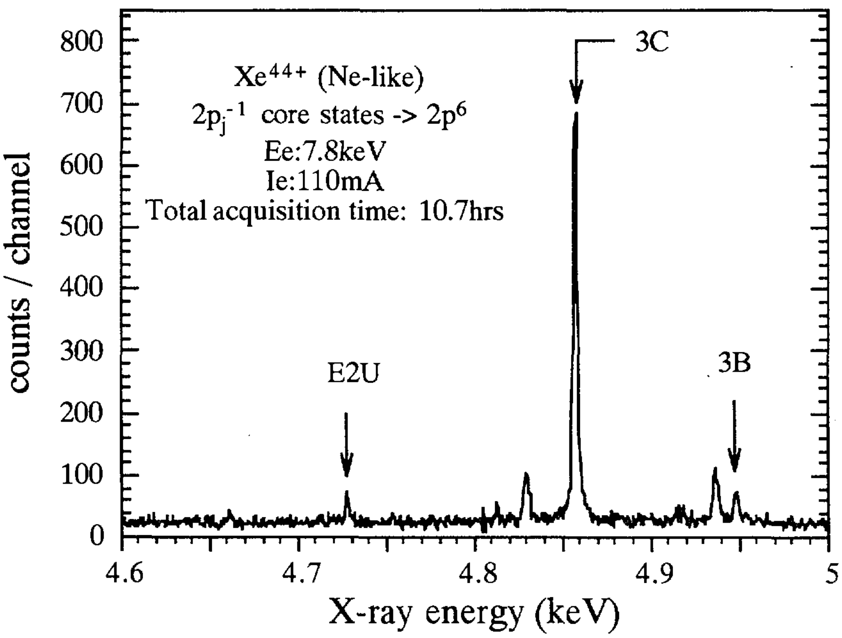


Figure 3

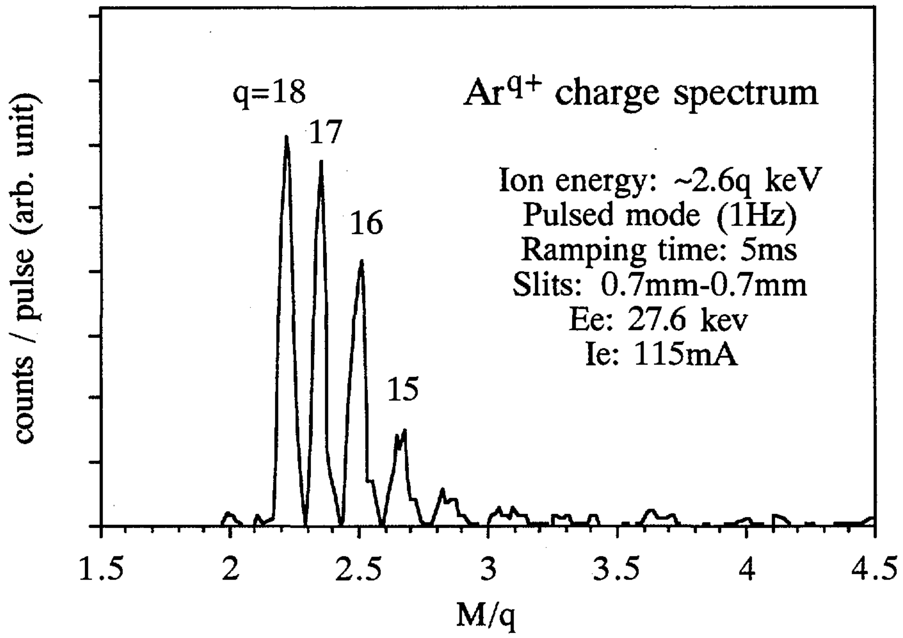


Ba46+ (Ne-like)
2p3/2-1 core states -> 2p6
Ee:7.8keV
Ie:110mA
Total acquisition time: 6.7hrs
3D
(3d5/2)2
3E
3F
E2L
E2M
counts / channel
X-ray energy (keV)



Xe44+ (Ne-like)
2pj-1 core states -> 2p6
Ee:7.8keV
Ie:110mA
Total acquisition time: 10.7hrs
3C
E2U
3B
counts / channel
X-ray energy (keV)

Figure 4


Ar^{q+} charge spectrum
Ion energy: ~2.6q keV
Pulsed mode (1Hz)
Ramping time: 5ms
Slits: 0.7mm-0.7mm
Ee: 27.6 kev
Ie: 115mA
q=18
17
16
15
counts / pulse (arb. unit)
1.5
2
2.5
3
3.5
4
4.5
M/q

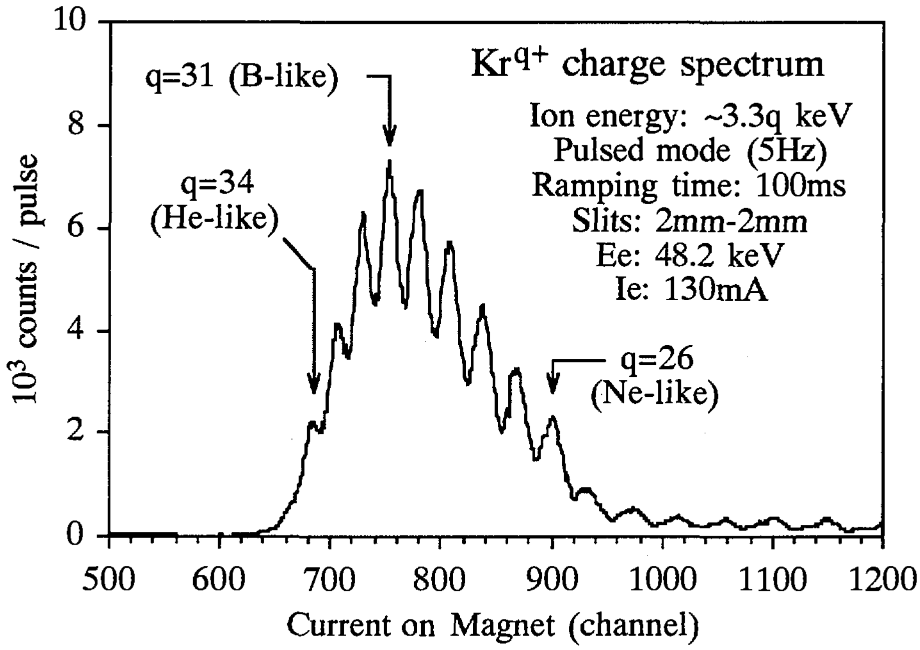

Kr^{q+} charge spectrum
Ion energy: ~3.3q keV
Pulsed mode (5Hz)
Ramping time: 100ms
Slits: 2mm-2mm
Ee: 48.2 keV
Ie: 130mA
q=31 (B-like)
q=34
(He-like)
q=26
(Ne-like)
10^3 counts / pulse
10
8
6
4
2
0
500
600
700
800
900
1000
1100
1200
Current on Magnet (channel)

Figure 5

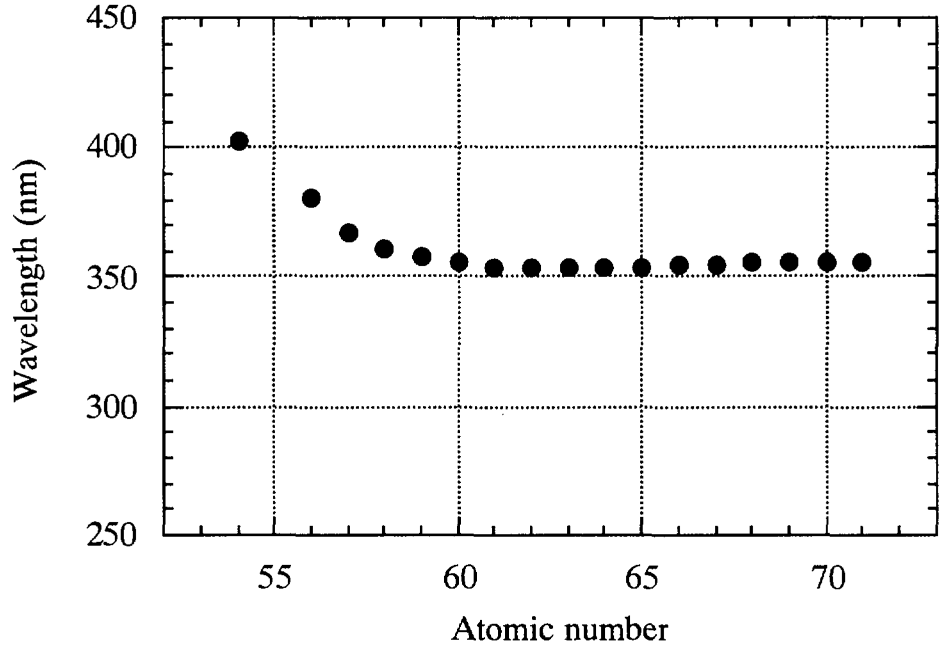


Figure 6