Chapter 6

CONCLUDING REMARKS

The present study is to investigate a number of low-temperature thermo-fluid dynamic phenomena of superfluid helium ($HeII$) by utilizing the newly developed superfluid shock tube facility. The target researches are two modes of shock waves, that is a compression and a thermal shock waves and the λ-phase transition from $HeII$ to HeI induced by shock compression. In this thesis, a compression and a thermal shock waves and the λ-phase transition are investigated by using the piezo-type pressure transducers and high response superconductive temperature sensor and Schlieren visualization method. The concluding remarks of this thesis are summarized as follows.

I. The nature of a gasdynamic shock wave propagating in low-temperature environment is investigated to verify the operational characteristic of the newly developed superfluid shock tube facility and to demonstrate its validity for the study subjects. It is confirmed that the superfluid shock tube facility can be used for the studies of shock waves in $HeII$ and highly transient λ-phase transition phenomena.

1. The intensity of the shock waves generated by the superfluid shock tube facility is qualitatively in good agreement with the Rankine-Hugoniot (*R-H-Gas*) relation. The reproducibility in shock wave formation is very good at both room and cryogenic temperatures.
2. The pressure gradually increases behind a shock wave in the case of propagation through a gas under a strong temperature gradient.
3. A gas dynamic shock wave can be efficiently transmitted into $HeII$

due to good shock impedance matching for gas-liquid interface, and a compression shock wave in *HeII* can penetrate through the interface back into vapor phase.

4. The gasdynamic shock wave satisfies the shock wave condition. The pressure rise ratio p_{21} and the shock Mach number M_{SV} measured experimentally well agree with the relation derived from the *R-H-Gas* relation, though it is weaker than the prediction on the basis of the initial pressure ratio, p_{41}.

II. Characteristics of a compression shock wave propagating through *HeII* is investigated by the superfluid shock tube facility. The numerical solution of Rankine-Hugoniot relation for *HeII* is compared with the present experimental results for compression shock waves.

1. The transmitted compression shock waves propagate at a shock Mach number M_{SL} about $1.00 \sim 1.15$, which indicates they are rather strong shock waves in liquids.

2. The temperature jump induced by a compression shock wave indicates an obvious temperature decrease in the process. The magnitude of ΔT increases with the wave strength M_{SL}.

   The temperature decrease of the experimental data points are in good agreement with the *R-H-HeII* relation.

3. The pressure and temperature jump data of the experimental results are in good agreement with the numerical solution of the *R-H-HeII* relation.

4. The propagation speed of the reflected shock wave in *HeII* from the shock tube bottom becomes faster than that of incident shock wave.

III. The thermal shock wave induced by a gasdynamic shock impingement is investigated by measuring the temperature variation with the superconductive temperature sensor.

1. The thermal shock wave generated in this experiment has very large amplitude and the temperature profile is found to be a single triangular

waveform almost irrespectively of the impinging shock strength. It is very similar to the limiting profile. The strength of limiting-profile-thermal-shock-wave increases almost linearly with the pressure jump Δp.

2. In the method of thermal shock wave generation by a gasdynamic shock wave impingement, the thermal shock wave with large amplitude can be generated.

3. It is found that the thermal shock wave is generated not at the moment of the impingement nor at the location of the initial free surface, but it is formed at slightly lower than the original free surface. A thermal boundary layer with a thickness of several mm is formed between the impinging supercritical helium vapor portion and the compressed $HeII$.

IV. $HeII$ can be shock-compressed to convert to HeI across the λ-line in the case of $HeII$ initially at temperatures rather close to the λ-temperature. In the present experiment, the λ-phase transition form $HeII$ to HeI is induced by shock compression in the shock tube.

1. The highly transient λ-phase transition is detected by a superconductive temperature sensor, where the temperature variation is positive, in striking contrast to the temperature drop that occurs during the $HeII$ to $HeII$ shock compression without the λ-transition .

2. $HeII$ converts to HeI by crossing the λ-line due to shock compression without any appreciable time delay. Since a positive temperature jump appears from the beginning of the shock compression, it can be concluded that the λ-transition occurs in a relatively short time even under this highly transient compression induced by shock waves.

3. The special case of λ-transition resulting from shock compression by reflected compression shock wave from the shock tube bottom is also detected. .

4. When the λ-transition occurs, no thermal shock is induced as a natural consequence of phase transition to HeI.

5. The shock adiabatic curve of liquid helium is experimentally obtained. The data is found to well agree with an isentropic curve calculated for *HeII*. However, in the shock compression process crossing the λ-line, the entropy is appreciable produced and thus the temperature rises significantly. The reason why such a large deviation from the adiabatic curve appears in this case is not yet wholly clear, though such aspect can be pointed out as the physical anomaly around the λ-line.