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The Review of the Phase Transition Radiation

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Abstract

The paper considers the infrared characteristic radiation (IRCR) during the first order phase transitions (crystallization, condensation and sublimation) of water. The experimental results show that when the particles (atoms, molecules, clusters) transfer from a higher energetic level to a lower level, partly of the latent heat will be liberation as the photon. By analyzing and summing up of a large number of references, in this paper, the radiative transfer mechanism is given and the radiative transfer equation is shown correspondingly. Besides, this paper also discusses the experiment of the phase change of water vapor condensation. IRCR can be used to solve some climate problems as well as the energy problem. The purpose of the paper is to have a study of the phase transition process, which will be helpful to us to have a further research about the cloud infrared laser that will contribute to search a forth source of ecologically pure energy by make full use of the energy in the clouds.

Keywords: IRCR; water vapor condensation; photon; radiative transfer mechanism; cloud infrared laser.

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1. Introduction

In the known theory, the latent heat is considered to be taken away from the vapor-liquid interface at constant temperature via heat conduction during vapor condensation [1~3].However, it can be represented as logically inconsistent: heat conduction depends on a difference of temperature and is a continuous process, while phase transition can be occurred at constant temperature and is made up of a set of discrete process. Since the 1960s, it has been suggested by Perelman that latent heat liberation may be realized completely or partly by emission of photons, in the frame of quantum electrodynamics. The first order phase transitions can be described as transitions of particles (atoms, molecules, or clusters) from a higher

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energetic level in a metastable phase to a lower level in a stable phase that produces emission of one or more photons. The phenomenon has been proven by the experiments. Perelman and his colleagues performed the experiments about vapor condensation and crystallization at vacuum condition, as a result they detected the wavelength of infrared radiation which was 4~8μm and 28~40μm correspondingly [4]. Tatarchenko and his colleagues have a found that many substances(among them are water, mangy alkali halides, lead chloride,sapphire,tellurium,germanium,sodium thiosulphate and some metals)[5~7],the latent heat of melting is radiated by the melt crystallization into solid state, as well as for water vapor, that the latent heat is radiated by the vapor condensation into liquid state[8].There are numerous experimental and theoretical evidences proving that the infrared characteristic radiation(IRCR) of first order phase transitions exist.

In the literature, the first order phase transition of water is of great interest to many scientists in the IRCR study. In this paper, we mainly present the research about the vapor condensation; we will discuss the experiment results about the phase-transition radiation, the radiative transfer mechanism on the vapor condensation, the radiative equation and the prospect of the study.

2. IR Radiation accompanying the water phase transitions

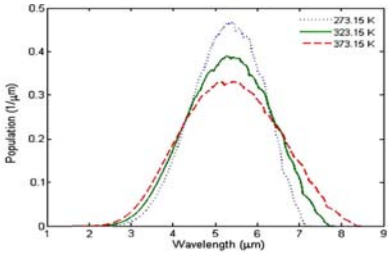

Fig.1. Population distribution functions at different temperature for 2-a transition

Here we present some experimental and theoretical results concerned with the IRCR during the water vapor phase-transition.

In [9], Nichols and Lamar developed an infrared line scan camera that can scan an object simultaneously over three separate spectral ranges and produce an image of the object as a color photograph. The authors found sources of infrared radiation in the range of 8~14μm in the atmosphere by analyzing the numerous impressive pictures. The radiation can be associated neither with temperature, nor with reflective radiation. These sources were the bottom sides of cumulus clouds with a temperature of -5℃ and the rising warm air saturated with water vapor.

In [10], Potter and Hoffman describe the anomalous phenomenon as phase-transition luminescence to address the intensity increase in an apparatus comprising a vessel with boiling water. Their research suggests that the integrated intensity was four times higher than Plank's radiation in the range of 1-4μm.Two main emission bands were set in the range of 2.10μm and 1.54μm.Compared with the background radiation, it is easy to find that the intensity of both bands exceeded by a factor of ten.

In [11], Mestvirishvili and Perelman carried out the experiments on the water crystallization and vapor condensation in a closed chamber. The results allowed the authors to affirm that they had recorded the phase transition in the range of 4~8μm for the vapor condensation and in the range of 28~40μm for the water freezing. They suggested that the latent heat can be liberated as one photon one bond. It means that the latent heat released in the phase transition could be converted to the photons.

In [12], Kuo-Ting Wang and Brewster investigated the radiative relaxation of condensation radiation and had a calculation and analysis of the characteristic wavelength of condensation radiation. In their paper, two figures were shown. In fig.1 the peak of the population distribution function at normal temperatures matches the experimental characteristic wavelength for vapor condensation,4~8μm.

In [13],according to Curtis, who mainly do the work of the analysis of the water vapor images which was obtained by the Japanese weather satellites of series GMS 5-GMS 9,presented the research that the center of infrared wavelength is 6.7μm.Recording radiation emitted by water vapor in the upper troposphere.

3. Radiative transfer mechanism

In the literature (Kuo-Ting Wang and Brewster, 2010), the study of radiative transfer mechanism has been drawn much attention. We accept that when the particle (atom, molecule, cluster) changes into a new phase, it can radiate one or several photons in the form of the latent heat. The characteristic radiation for vapor condensation is closely related to the problem of how a water vapor molecule condenses. In the whole process of condensation, when a vapor molecule is attached to other liquid-water molecules, the potential energy of the bulk water drops, at the same time, the average number of hydrogen bonds per bulk water molecule increases. Consequently, the whole process of the vapor condensation can be considered that include many steps. The beginning of the process is the de-excitation of the water vapor molecule which is in the excited state in a metastable phase. Continuing with the formation of the hydrogen bonds and the emission of the photons, the process can be called the intermediate state. The end of the process is the reach of the thermal equilibrium. The process is shown in the fig.2.

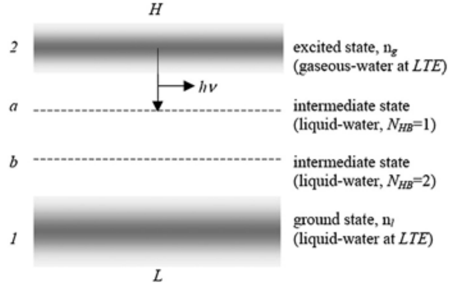

Fig.2. Radiative relaxation during vapor condensation

So now we are interested in the question that how the radiation happens in relation to water vapor condensation. The process of phase transition radiation can be divided into two parts: radiative photon relaxation and non-radiative phonon relaxation. Apparently, non-radiative relaxation is more essential than radiative relaxation if the transition goes through a lot of steps. So in order to explain the characteristic radiation of vapor condensation, we propose that, the radiative photon relaxation takes place at the initial stage (state 2 to a), while non-radiative relaxation happens at the following stages (state a to 1).The state a is the intermediate state which is far more probable to form one hydrogen bond than multiple hydrogen bonds at once. The state 2 to a is considered to be a continuous process instead of discrete radiation pulse. The state b only means an intermediate state in the non-radiative relaxation process. This mechanism of condensation radiation is based on the existing experimental evidences. The state 2 to a is the process that emitting photons, while the state a to 1 is the process that the latent heat released via heat conduction.

4.Radiative transfer equation

When the water molecules are de-excited from gas-state to liquid-state, the gap of the energy between the states is emitted through the photons or phonons. It has been pointed out that for a radiative phase transition, only when the time of the optical transition is less than or comparable to the time of the non-radiative relaxation, the photons will be released in the process of radiative relaxation [14].

The radiative transfer equation (Kuo-Ting Wang and Brewster, 2010) for condensation process can be presented in the later description. Assuming the molecules are at LTE (local thermal equilibrium), and the effect of the lower energy level population distribution is ignored, and the radioactive relaxation time depends on the Einstein's coefficient for spontaneous emission. Considering the absorption bands of the non-phase-change molecular and the condensation radiation, the radiative transfer equation is given by

$$\frac{dI_v}{ds} = -(K_{a_v} + K_{c_v})I_v + (K_{a_v} + K_{c_v})B_v \tag{1}$$

Where I_v is the specific intensity in frequency υ basis, ds is the path length, Ka_v is the non-phase-change absorption coefficient of a typical radiation field in the absence of condensation radiation, Kc_v is the absorption coefficient due to condensation radiation, B_v is Planck's function for blackbody radiation. The solution of the radiative transfer equation (1) is shown in (2),

$$I_v = e^{-\int (K_{a_v}+K_{c_v})ds} \cdot I_{v_0} + [1 - e^{-\int (K_{a_v}+K_{c_v})ds}] \cdot B_v \tag{2}$$

Where Iv_0 is the specific intensity at boundary.

For condensation radiation, if Kc_v has to be comparable with or larger than Ka_v, the characteristic radiation relaxation can release photons and is not covered by non-phase-change radiation. To minimize the shadowing effect by non-phase-change radiation, the spectrum should be chosen around the 4μm of the atmospheric windows, it is because the water vapor has very low Ka_v in such wavelength.

The phase transition radiation can release a single photon,and also can emit a few photons whose frequency are the same or different.So,there are such opportunities of radiation[15]:

(1) If radiation has one-photon character,

$$h\omega_1 = \Lambda / N_A \;\; or \;\; \lambda_1 = 120/\Lambda\,; \tag{3}$$

Where $h\omega_1$ is the energy of one-photon, N_A is the Avogadro number, λ_1 is the lengths of waves, Λ is expressed as the latent heat of the phase-change.

(2) The n-photon transition with equal frequencies,

Assuming the one-particle releases n-photon that with equal frequencies when phase changes,then the photon energy and wavelength respectively is,

$$h\omega_n = \Lambda / nN_A \;\; or \;\; \lambda_n = 120n/\Lambda\,. \tag{4}$$

(3) If the bound energy of atoms/molecules in the particles(dimers, more complicate formations, clusters)is small enough, then wavelengths of radiation for a cluster of M particles will be of the type:

$$\lambda_n^{(M)} \approx 120n/M\Lambda\,; \tag{5}$$

There are three different phase-change of water [16]:

condensation-$\lambda^{(C)}$,freezing- $\lambda^{(F)}$,deposition- $\lambda^{(D)}$.Assuming that one single molecular can release two photons during phase transition. Then according to the equation (4), three characteristics wavelength of the three phase change can be obtained:

$$\lambda_2^{(C,1)} = 5.80\,\mu m;\ \lambda_2^{(F,1)} = 39.24\,\mu m;\ \lambda_2^{(D,1)} = 5.06\,\mu m\ . \qquad (6)$$

For two photons produced, taking into account Doppler's broadening of the characteristic radiation, the ranges for $\lambda_2^{(C,1)}$ and $\lambda_2^{(F,1)}$ were estimated by Mestvirishvili and Perelman: $\lambda_2^{(C,1)}$ =(5.2~6.4)μm and $\lambda_2^{(F,1)}$ =(34~42)μm.

This data was consistent with the experimental results conducted by Perelman.Now there are many infrared images about earth that taken from the space. Specially, 6.7~6.9μm was used to record the water vapor of the earth. And the spectrum is similar to the $\lambda_2^{(C,1)}$.

The radiation peaks at 3.2μm,2.10μm and 1.54μm from Potter and Hoffman experiments, when taking into account the relation(5),can be attributed to the emission of two photon radiation during condensation of water dimmers and higher molecular complexes.

5.Experiment of water vapor condensation

According to the references(Mestvirishvili and Perelman,1977),the experiment performed by Mestvirishvili and Perelman for the semiqualitative estimate of the water phase transition is presented in this paper.This experimental set-up for the investigation of the vapor-water transition is shown in fig.3.The results of experiment was detected by the infrared bolometer which included in the Wheatstone bridge(through testing the numerical value of the current or voltage to compare with photon energy at the different spectrum) out a microvoltmeter.When plunger is lifted up, the vessel is full of the saturated vapor. The reverse plunger motion leads to a 0.1g vapor condensation on the average. With the latent heat is released, photons is produced in the vessel. The photon goes through the Ge window which is glued to the 20μm thick copper foil, in order to convert the whole radiation to Planck's distribution. If the system is lack of filter, then the energy of radiation no less than 3％of the latent heat is registered. And two kinds of filters are used in the experiment. The 200μm thick glass filter which can avoid the wavelength that above 4μm going through, as a result it practically impedes altogether the radiation. The 200μm thick mica filter, transparent until 8μm,weakens the initial flux by 20％ only. The experimental results can prove that vapor-water transition generates photons with maximum 4~8μm.

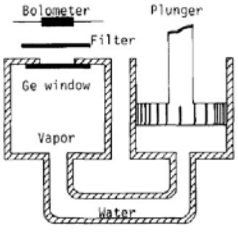

Fig.3.The experiment of the water vapor condensation

6.Conclusions

Although the technology of the phase transition radiation still to be investigated. It is a good tendency that shown in the use of this phenomenon to solve some climate problems and energy problems [17].

(1)Infrared lasers could be made on the basis of water vapor condensation or freezing in atmosphere. So we can develop a cloud infrared laser to make full use of the energy of clouds. Let us image a system of two parallel mirrors on an area of 1m^2 each from other. A bunch of the infrared beam with specific wavelength rips into the water vapor, and does the reciprocating motion in the system, which can lead to more photons released during the water vapor condensation, and the photon can be used to generate power. In this case about 10g of water vapor will be condensed, which means about 25KW of the energy will be liberated. If the efficiency of the laser is 8%,then about 2KJ of the energy will be accumulated. The efficiency of system is 20 times higher than the traditional silicon solar battery.

(2)Formation of climate problems (hail in storm clouds, devastating hurricane and strong storm) in the atmosphere has to be accompanied by intensive characteristic infrared radiation, which could be used to predict and warn of damaging of the climate problems.

(3)With the help of the infrared radiation detection, we can determine whether there is water in the atmosphere of other planets. The radiation may explain Jupiter's red color and its infrared emission. The characteristics infrared radiation can be used for the cooling of the earth.

(4)The techniques of the phase transition can be used to develop new processing technology of the material.

References

[1].V.P. Carey, Liquid-vapor Phase-change Phenomena: An Introduction to the Thermophysics of Vaporization and Condensation in Heat Transfer Equipment, Taylor & Francis, 2007, pp. 347–353.

[2].W.L. McCabe, J.C. Smith, P. Harriott, Unit Operations of Chemical Engineering, sixth ed., McGraw-Hill, New York, 2001, pp. 377–389.

[3].A.F. Mills, Heat and Mass Transfer, Richard D. Irwin, Inc., 1995, pp. 600–622.

[4].Mestvirishvili, A.N., Directovich, J.G., Grigoriev, S.I., Perel'man, M.E., 1977. Characteristic radiation due to the phase transitions latent energy. Physics Letters 60A, 143–144.

[5].Tatarchenko VA. Appearance of distinguishing features in emission spectra during crystallization of substances transparent in the IR region. Soviet Physics—Crystallography1979; 24:238–9.

[6].Tatarchenko VA, Umarov LM. Infrared radiation accompanying the crystallization of sapphire. Soviet Physics—Crystallography 1980; 25:748–9.

[7].Umarov LM, Tatarchenko VA. Differential spectra of crystallization radiation of alkali-metal halides. Soviet Physics—Crystallography 1984; 29:670–3.

[8].Perel'man, M.E., 1971. Phase transitions caused by the opening of new channels in electron–photon interactions. Physics Letters A 37, 411–412.

[9].Nichols, L.W., Lamar, J., 1968. Conversion of infrared images to visible in color. Applied Optics 7, 1757–1762.

[10].Potter, W.R., Hoffman, J.G., 1968. Phase transition luminescence in boiling water;evidence for clusters. Infrared Physics 8.

[11].Mestvirishvili, A.N., Directovich, J.G., Grigoriev, S.I., Perel'man, M.E., 1977. Characteristic radiation due to the phase transitions latent energy. Physics Letters 60A, 143–144.

[12].Kuo-Ting Wang, M.Q Brewster. Phase-transition radiation in vapor condensation process，International Communications in Heat and Mass Transfer 37 (2010) 945–949.

[13].Curtis, A.R., 1994. Space Satellite Handbook. Gulf Publishing, TX. 346 p.

[14.Sall' SA, Smirnov AP. Phase-transition radiation and the growth of a new phase. Technical Physics 2000; 45:849–53.

[15].Perel'man, M.E., Tatartchenko, V.A., 2008. Phase transitions of the first kind as radiation processes. Physics Letters A 372, 2480–2483.

[16].Tatartchenko, V.A., 2010b. Infrared characteristic radiation of water condensation and freezing in connection with atmospheric phenomena. Earth-Science Reviews 101(1–2), 24–28.

[17].Tatartchenko, V.A., 2009a. Some peculiarities of first order phase transitions. Reviews on Advanced Material Science 20, 58–69.