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Rate Parameters for Electronic Excitation of Diatomic Molecules: NO Radiation

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This is one of an ongoing series of papers on collisional excitation of electronic states in N_2, O_2, NO, CO, CN, and N_2^+. In this paper, NO radiation observed in the test section of an arcjet wind tunnel is studied. In the experiments, NO γ and δ were seen, β was not seen, and ε was seen to be very weak. NO radiation is calculated with the use of the code SPRADIAN07 to explain the measured spectra. It was found that inverse predissociation is mainly responsible for the population of the NO $C^2\Pi_r$ state during recombination of N and O atoms. The population of the NO $A^2\Sigma^+$ state is mostly due to the radiative decay from the NO $C^2\Pi_r$ state. The NO $D^2\Sigma^+$ state is excited from the $C^2\Pi_r$ state by collisions. The NO $B^2\Pi_r$ state is populated by complicated collisional transition paths by passing through the intermediate states $a^4\Pi_r$ and $b^4\Sigma^-$. These interpretations at least qualitatively explain the experimental data. Electronic excitation temperature is only remotely related to electron temperature.

Nomenclature

A	=	electronic state of the NO molecule, $A^2\Sigma^+$
A_h	=	excitation rate parameter, cm^3/s
A_r	=	radiative transition probability, s^{-1}
a	=	electronic state of the NO molecule, $a^4\Pi$
B	=	electronic state of the NO molecule, $B^2\Pi_r$
b	=	electronic state of the NO molecule, $b^4\Sigma^-$
C	=	electronic state of the NO molecule, $C^2\Pi_r$
D	=	electronic state of the NO molecule, $D^2\Sigma^+$
E	=	electronic term energy, cm^{-1}; energy, cm^{-1}
g	=	statistical weight (multiplicity, degeneracy)
h	=	Plank constant, 6.6261×10^{-34} J · s
I	=	total band intensity, $W/(cm^3)$
I_λ	=	specific intensity, $W/(cm^2 \cdot \mu m \cdot sr)$
i	=	electronic state i of the NO molecule
J	=	rotational quantum number; rotational state
j	=	electronic state j of the NO molecule
K_e	=	excitation rate by electron collision, cm^3/s
K_h	=	excitation rate by heavy-particle collision, cm^3/s
K_{ivpr}	=	rate coefficient for inverse predissociation, cm^3/s
K_{prd}	=	rate coefficient for predissociation, s^{-1}
k_B	=	Boltzmann constant, 1.3807×10^{-23} J/K
k_λ	=	absorption coefficient, cm^{-1}
M	=	colliding heavy particle or electron
m	=	mass, g/mol
n	=	number density, cm^{-3}; excitation rate parameter, Eq. (10)
p	=	pressure, atm
Q	=	partition function
S	=	spin angular momentum quantum number
$S_{J''\Lambda''}^{J'\Lambda'}$	=	rotational line strength factor (Hönl–London factor)
s	=	distance along a ray, cm
T	=	heavy-particle translational temperature, K
T_d	=	activation temperature, K
T_e	=	electron temperature, K
T_{ex}	=	electronic excitation temperature, K
T_r	=	heavy-particle rotational temperature, K
T_v	=	vibrational temperature, K
t	=	time, s
v	=	vibrational quantum number, vibrational state
X	=	ground electronic state of the NO molecule, $X^2\Pi_r$
x	=	distance from the nozzle exit
β	=	NO $B^2\Pi_r - X^2\Pi_r$ transition
γ	=	NO $A^2\Sigma^+ - X^2\Pi_r$ transition
δ	=	NO $C^2\Pi_r - X^2\Pi_r$ transition
δ_K	=	Kronecker delta
ε	=	NO $D^2\Sigma^+ - X^2\Pi_r$ transition
ε_λ	=	emission coefficient, $W/(cm^2 \cdot \mu m \cdot sr)$
κ	=	nonequilibrium factor
λ	=	wavelength, Å or nm
Λ	=	orbital angular momentum quantum number about the internuclear axis
ν	=	frequency, Hz
σ	=	cross section, cm^2
χ	=	total mole fraction

Subscripts

A	=	electronic state of the NO molecule, $A^2\Sigma^+$
a	=	electronic state of the NO molecule, $a^4\Pi$
B	=	electronic state of the NO molecule, $B^2\Pi_r$
b	=	electronic state of the NO molecule, $b^4\Sigma^-$
C	=	electronic state of the NO molecule, $C^2\Pi_r$
D	=	electronic state of the NO molecule, $D^2\Sigma^+$
e	=	electron
eq	=	under Boltzmann distribution
h	=	heavy particle
i	=	electronic state i of an atom or molecule
nq	=	under non-Boltzmann distribution
t	=	total
X	=	ground electronic state of an atom or molecule

Superscripts

$'$	=	upper state
$''$	=	lower state

I. Introduction

ARCJET wind-tunnel facilities have been used to test thermal protection materials. Arcjet nozzle flows have been known to be in thermal and chemical nonequilibrium. Many experimental and theoretical efforts have been made to characterize such flows.

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