Inter-atomic photon emission during contact-electrification

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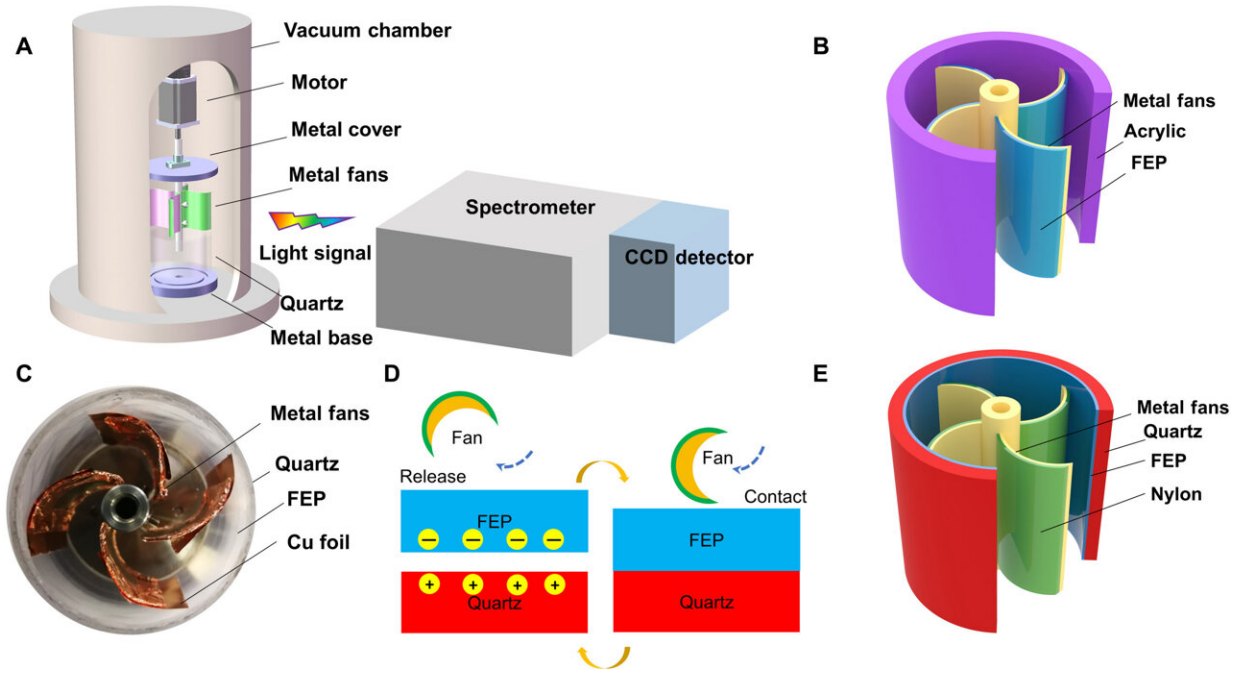


The schematic diagram of experiments. (A) CE parts in vacuum chamber and spectrometer. (B) Measurement mode A: FEP on fans and directly contact with quartz or acrylic. (C) Optical photograph of the CE parts. (D) The working principle of the measurement mode B. (E) Measurement mode B: FEP attached to quartz or acrylic with nylon, etc. on fans. Photo credit: Ding Li, Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences. Credit: Science Advances, doi: 10.1126/sciadv.abj0349

Contact electrification can arise when physical contact occurs between

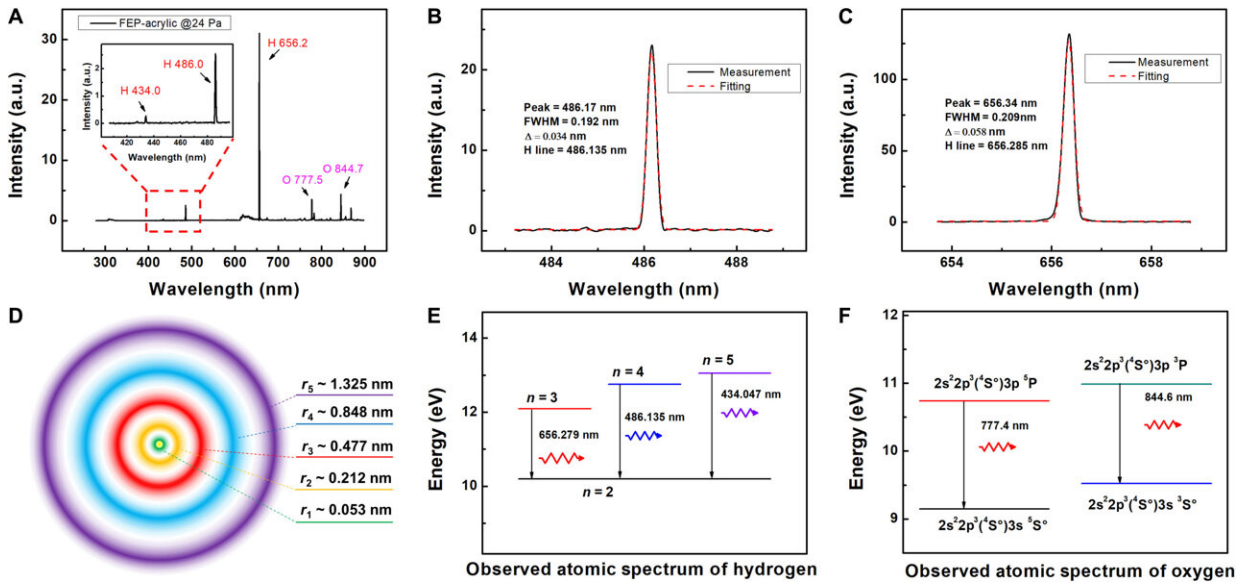
two materials. In a new report now published on *Science Advances*, Ding Li, and a team of scientists in nanoscience, nanoenergy and materials science in China and the U.S., detailed atomic-featured photon emission spectra between two solid materials. Electron transfer can take place at the interface from an atom in one material to another atom in another material, alongside photon emission, during contact electrification.

This process can assist contact electrification induced interface photon emission spectroscopy (CEIIPES) to detect spectroscopy corresponding to contact electrification at an interface, and impact the awareness of interactions between solids, liquids and gases. The physics of this research can be expanded to X-ray emission, Auger electron excitation and electron emission during contact electrification, which remains to be explored. The work leads to a general field known as contact electrification induced interface spectroscopy (CEIIS).

Triboelectrification

Contact electrification is a scientific term used for the well-known phenomenon of triboelectrification and defines the charges produced by physical contact. The concept is universal in both daily life and in nature, occurring between shoes and the ground, when clouds move in the air and when the Earth shakes. While the process was first recorded more than 2600 years ago, scientists still debate the mechanism behind the process. Research in the field has evolved with modern technologies to describe the true complexity of the phenomenon, although some observations are inexplicable or contradictory. In this work, Li et al observed atomic featured photon emission spectra during contact electrification at a solid-solid interface by contacting fluorinated ethylene propylene (FEP) with acrylic, or FEP with quartz. Compared to triboluminescence, the characteristic photon emission induced by contact electrification can carry abundant information about the energy structure at interfaces. Li et al suggested three possible physical

processes to understand photon emission arising from electron charge transferred during charge electrification. The process is known as contact electrification induced interface photon spectroscopy (CEIIPES) and can allow researchers to study electronic transitions at solid-solid interfaces.



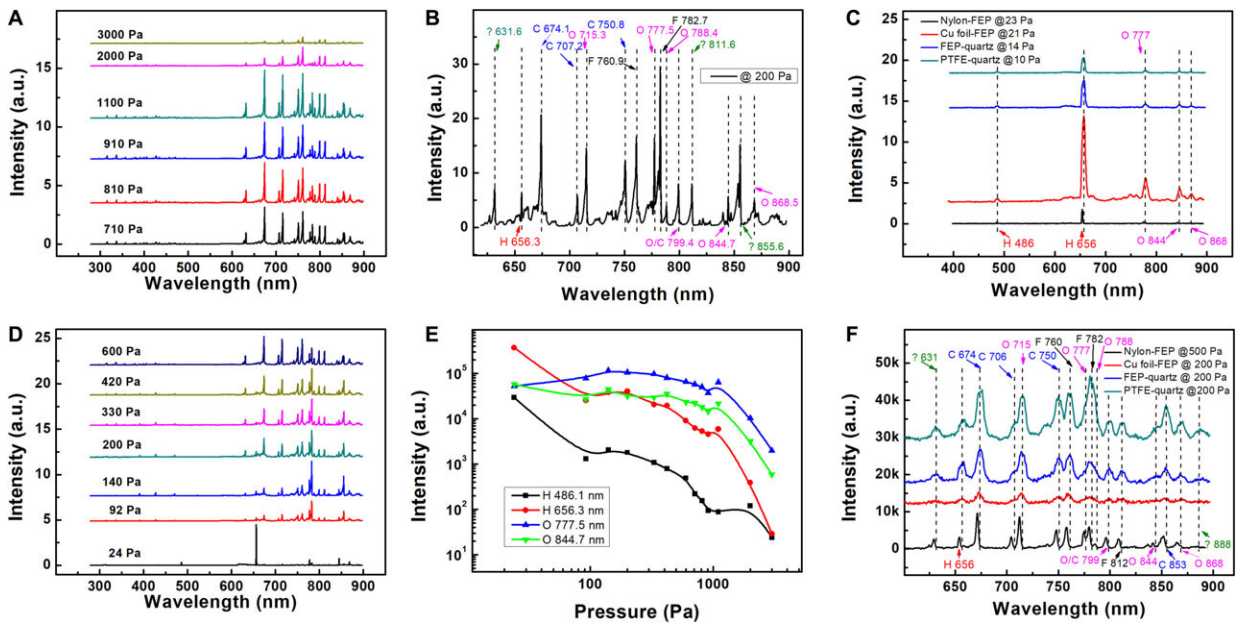
Interface electron transition induced photo emission spectra and related energy levels in CE at low pressure for the FEP-acrylic group. (A) The spectra recorded at 24 Pa with identified hydrogen and oxygen atomic spectra. a.u., arbitrary units. (B and C) For hydrogen spectra, higher-resolution grating was used for further confirmation. (D) Electron energy radius on Bohr model of hydrogen atom. (E and F) Energy levels for identified atomic lines in (A). Credit: Science Advances, doi: 10.1126/sciadv.abj0349

The working principle of contact electrification (CE)

Li et al formed the core parts of a hollow cylinder sandwiched between a metal cover and a metal base, within which they drove four metal fans

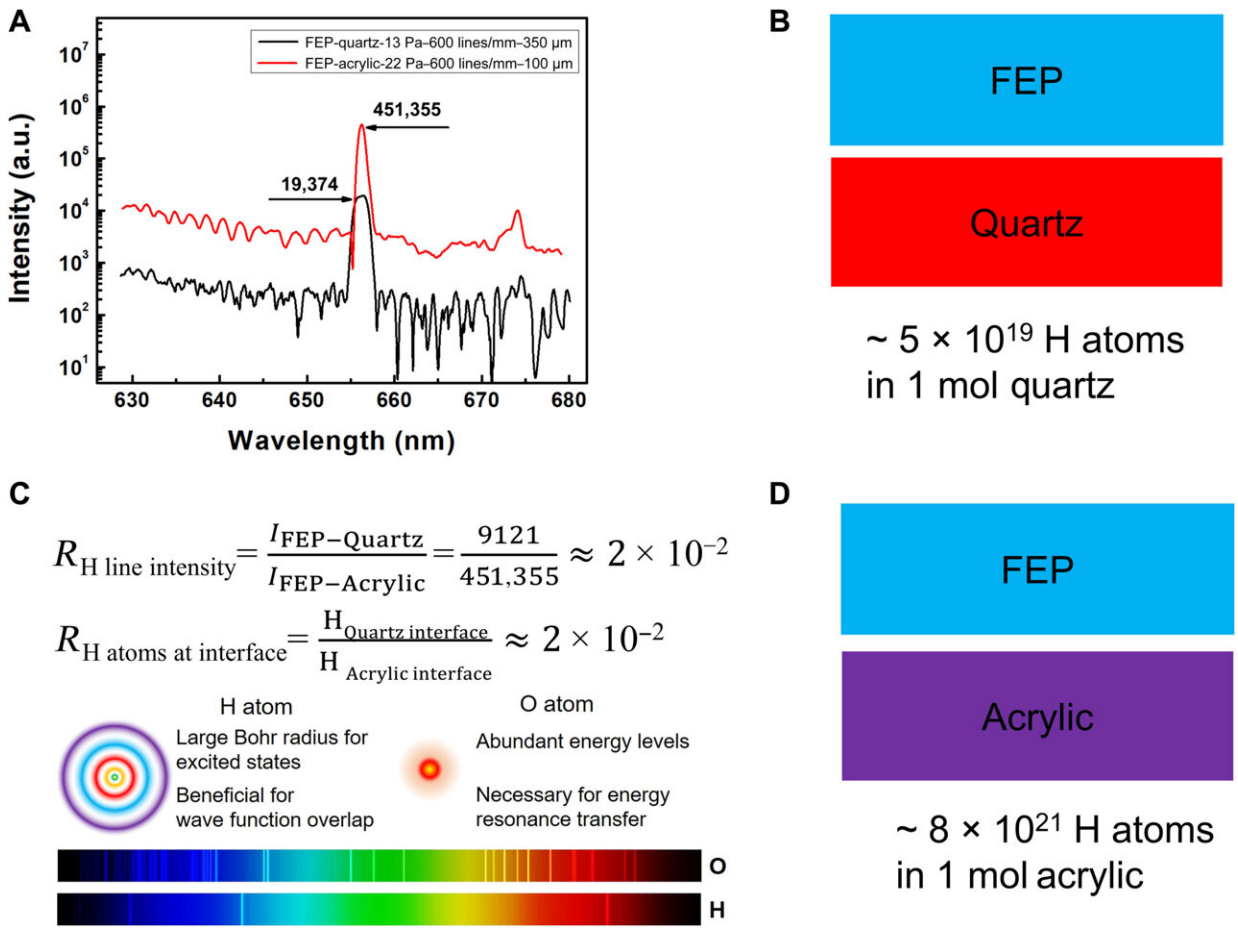
using a motor. The team attached the materials for contact electrification (CE) to the metal fans or to the cylinder, and induced CE at the interface during fan rotation. They measured the pressure using a pressure motor and controlled the differential flow of the inlet and outlet of the vacuum chamber through flow meters. If a photon signal originated from the core, they could record it using a spectrometer with a sensitive charge-coupled device detector. Li et al noted photon emission associated with the physical processes of CE. For instance, photon emissions with atomic spectra features were associated with electron transitions during contact electrification and the scientists defined this phenomenon as contact electrification induce interface photon emission spectroscopy (CEIIPES).

Physical processes of electron transfer

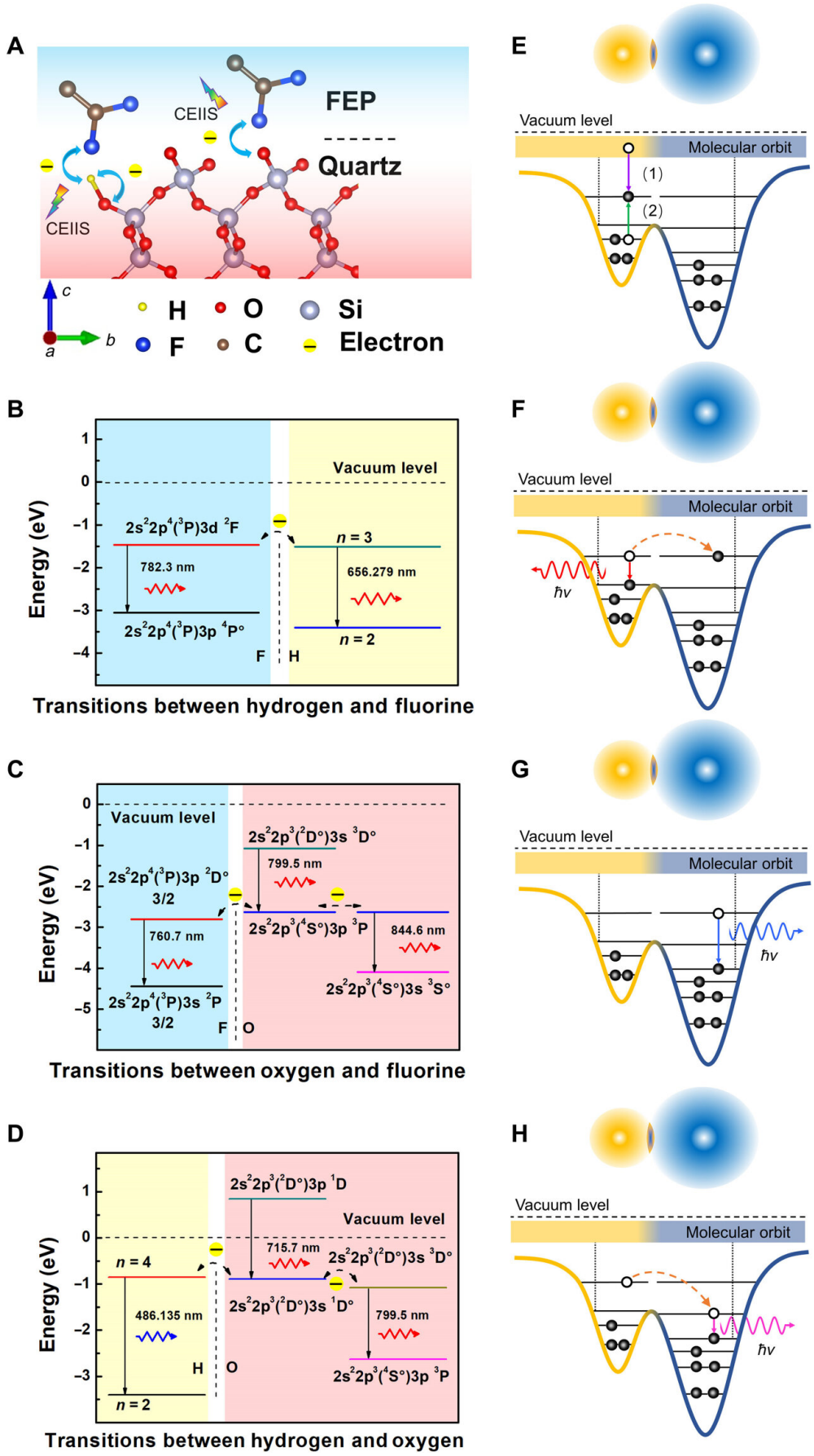


Interface electron transition induced photo emission spectra and related energy level in CE at different pressures for different contact materials groups. (A and D) CEIIPES of the FEP-acrylic group at different atmosphere pressures. (B) Enlarge and identifications of atomic lines in CEIIPES of the FEP-acrylic group

at 200 Pa. (C and F) CEIIPES of different groups at different atmosphere pressures with identifications of atomic lines. (E) The peak intensity of selected atomic lines changes with atmosphere pressure. Credit: Science Advances, doi: 10.1126/sciadv.abj0349



Interface electron transition induced photo emission intensity is comparable to the H atoms at the interfaces for FEP-acrylic group and FEP-quartz group. (A) Take the H 656.2-nm line for example and the corresponding illustrations in (B) and (D). (C) Color spectra of elements H and O in the range of 400 to 700 nm, showing different functions of them for electron transfer at CE. The ratio of intensity is comparable to the ratio of H atoms at the interfaces. Credit: Science Advances, doi: 10.1126/sciadv.abj0349


A
FEP
Quartz
CEIIS
CEIIS
c
a
b
H
O
Si
F
C
Electron
B
Vacuum level
Energy (eV)
2s²2p⁴(³P)3d ²F
782.3 nm
2s²2p⁴(³P)3p ⁴P°
n = 3
656.279 nm
n = 2
F
H
Transitions between hydrogen and fluorine
C
Vacuum level
Energy (eV)
2s²2p⁴(³P)3p ²D° 3/2
760.7 nm
2s²2p⁴(³P)3s ²P 3/2
2s²2p³(²D°)3s ³D°
799.5 nm
2s²2p³(⁴S°)3p ³P
844.6 nm
2s²2p³(⁴S°)3s ³S°
F
O
Transitions between oxygen and fluorine
D
Energy (eV)
2s²2p³(²D°)3p ¹D
Vacuum level
n = 4
715.7 nm
2s²2p³(²D°)3s ³D°
2s²2p³(²D°)3s ¹D°
486.135 nm
799.5 nm
2s²2p³(⁴S°)3p ³P
n = 2
H
O
Transitions between hydrogen and oxygen
E
Vacuum level
Molecular orbit
(1)
(2)
F
Vacuum level
Molecular orbit
ħv
G
Vacuum level
Molecular orbit
ħv
H
Vacuum level
Molecular orbit
ħv

Energy diagram for interface electron transition induced photo emission. (A) The schematic diagram of FEP and quartz interface at atomic level. (B) Energy diagram of electron transition between hydrogen and fluorine. (C) Energy diagram of electron transition between oxygen and fluorine. (D) Energy diagram of electron transition between hydrogen and oxygen. In addition, the schematic diagram of possible physical processes of electrons transitions and the associated photon emission, also known as Wang transition, when two atoms are close to each other (E to H). Credit: Science Advances, doi: 10.1126/sciadv.abj0349

The team next illustrated the physical processes underlying photon emission lines relative to the energy levels and electron transitions in the setup. For example, when the FEP material contacted quartz, electron transitions occurred for these materials including transitions between atoms such as hydrogen and oxygen at the surface of quartz. The team summarized the possible physical routes for electron transitions among different atoms during contact electrification and noted two possible methods for electron transition to excited states, including (1) electron transition from molecular orbit to the excited state of an atom, or (2) the excitation of an atom from a lower energy level to higher energy level inside an atom. Furthermore, an excited state electron can transit to a lower energy level by emitting a photon. Contact electrification induced interface photon emission spectroscopy (CEIIPES) is different from fluorescent spectra for molecules, where CEIIPES is associated with photon emission relative to electron transfer between two atoms. Comparatively, fluorescence spectra are associated with electron transition between molecular levels with many vibrational levels. The team then highlighted the role of the hydrogen atom during contact electrification, where H atoms possessed unique roles during the experiments. The present studies only demonstrated photon emission relative to CEIIPES at solid-solid interfaces, the team intend to use the

method and reveal more interesting phenomena at solid-liquid, solid-gas, gas-gas and gas-liquid, as well as liquid-liquid interfaces.

Outlook

In this way, Ding Li and colleagues observed atomic featured photon emission spectra during contact electrification between two solids. During the work, electrons transferred from one atom of a specific material to another atom in another material at the interface during contact electrification in a process known as contact electrification induced interface photon emission spectroscopy (CEIIPES). The process occurred through energy resonance transfer when atoms from different materials were brought close to each other. The team analyzed the processes underlying contact electrification to better understand how two materials were charged after contact electrification to assess interactions between liquids, solids, and gases. The work is specific to solid-solid interfaces and is applicable for more general cases such as X-ray emission and Auger electron excitation.

More information: Ding Li et al, Interface inter-atomic electron-transition induced photon emission in contact-electrification, *Science Advances* (2021). DOI: 10.1126/sciadv.abj0349

Walter Jamieson, The Electrification of Insulating Materials, *Nature* (2008). DOI: 10.1038/083189a0