Supplementary Information for

**Direct imaging of rotating molecules anchored on graphene**

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Supplementary Figure S1. Structural formula of C\textsubscript{60}-containing poly(norbornene) derivative ($m=3$). The detailed synthesis of molecules can be found in the previous report.\textsuperscript{S1}

Supplementary Figure S2. Time-dependent molecular configurations. (a-d) Angular configuration of molecule 1 for sequential time intervals. (e) The time evolution of occupancy of zigzag(ZZ) and armchair(AC) configurations. The thick lines are guides to the eye.
Supplementary Figure S3. Elastic scattering geometry for surface-directional momentum transfer from incident electron beam to carbon atom in molecule.

Supplementary Table 1. The analyzed data set of molecules to estimate the rotational energy barriers.

<table>
<thead>
<tr>
<th>Molecule #</th>
<th>Total # of atoms</th>
<th>Normalized event rate (s(^{-1}))</th>
<th>Surface energy barrier threshold (eV)</th>
<th>Energy barrier (meV / atoms)</th>
<th>Energy barrier per C(<em>{60}) (meV / C(</em>{60}) molecule)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>114</td>
<td>1.7±0.8</td>
<td>0.27</td>
<td>2.4</td>
<td>1.4 \times 10(^2) (lower limit) 9.7 \times 10(^1) (upper limit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.6 (lower limit) 4.7 (upper limit)</td>
<td>2.8 \times 10(^2) (upper limit)</td>
</tr>
<tr>
<td>2</td>
<td>267</td>
<td>2.7±0.8</td>
<td>0.40</td>
<td>1.5</td>
<td>8.9 \times 10(^1) (lower limit) 6.8 \times 10(^1) (upper limit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1 (lower limit) 2.1 (upper limit)</td>
<td>1.3 \times 10(^2) (upper limit)</td>
</tr>
<tr>
<td>3</td>
<td>279</td>
<td>0.15±0.10</td>
<td>3.3</td>
<td>12</td>
<td>7.0 \times 10(^2) (lower limit) 5.8 \times 10(^2) (upper limit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.6 (lower limit) 14 (upper limit)</td>
<td>8.2 \times 10(^2) (upper limit)</td>
</tr>
</tbody>
</table>
Supplementary Note 1

The Coulomb scattering theory for calculating event rate

The differential cross section of elastic scattering when surface transferred energy \( E \) is given can be written as

\[
\frac{d\sigma(E)}{dE} = \frac{\pi Z^2 \gamma^2}{k_0^4 a_0^2 E_{\text{max}} \left( 1 - \frac{1 - E}{E_{\text{max}}} \right)^2 \sqrt{1 - \frac{E}{E_{\text{max}}}}} \tag{S1}
\]

where \( Z \) is the atomic number of the target atoms, \( \gamma = \left( 1 - v^2/c^2 \right)^{-1/2} \) the Lorentz factor, \( k_0 \) the incident-electron wavenumber, \( a_0 \) and the Bohr radius of the hydrogen atom (5.3 \( \times \) 10\(^{-11} \) m), \( E_{\text{max}} \) is the maximum surface transferred energy and can be written as

\[
E_{\text{max}} = \frac{E_0 (E_0 + 2m_e c^2)}{2Mc^2} \tag{S2}
\]

under the assumption that the target atom mass \( M \) is much heavier than the electron mass \( m_e \) (\( E_0 \) is the kinetic energy of the incident electron). At 80 kV TEM operation, \( E_{\text{max}} \) is 3.95 eV for carbon atoms.

Supplementary References
