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Introduction

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Two-dimensional (2D) materials have been emerging stars in condensed matter physics, materials science, and chemistry since the successful exfoliation of graphene by Novoselov and Geim in 2004 [1–3]. The atomic thickness and micrometer lateral dimensions endow 2D materials with great potential in membrane separation. Synthetic membranes are used widely in many separation processes, from industrial-scale processes, such as removing salt from seawater and separating atmospheric gases, to smaller-scale processes in chemical synthesis and purification [4, 5]. The membranes function by forming a selective barrier between the two phases, restricting the movement of some molecules while letting others penetrate. On one hand, the membranes assembled from ultrathin nanosheets can minimize the transport resistance and maximize the mass-transfer rate. On the other hand, the intrinsic or artificial nanopores and interlayer galleries can provide excellent molecular sieving properties [6, 7]. Hence, 2D materials, including graphene-family, zeolites, metal–organic frameworks (MOFs), covalent–organic frameworks (COFs), metal carbides and nitrides (MXenes), and layered double hydroxides (LDHs), have been demonstrated as excellent building blocks for high-performance membranes [8, 9].

2D materials are either porous or nonporous based on their atomic structure. The intrinsic nanopores in zeolites and MOFs or the drilled nanopores in graphene can provide molecular/ionic transport pathway. In contrast, the nonporous nanosheets (e.g. graphene oxide and MXene) must be assembled into laminates with interlayer channels for mass transfer, which is driven by external forces, such as pressure difference, centrifugal force, and molecular interaction [10]. Hence, according to the difference in membrane structures, 2D-material-based membranes can be categorized into three types—(i) porous nanosheet membranes, (ii) laminar membranes, and (iii) 2D-material-based mixed-matrix membranes (MMMs). The fabrication methods and unique properties of these membranes will be detailedly discussed in the following chapters. By the precise construction and manipulation of the in-plane nanopores/slits and interlayer channels, 2D-material-based membranes

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have exhibited outstanding molecular separation properties in various membrane processes, such as ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, pervaporation, and gas separation [9].

With the rapid development of 2D-material-based membranes, a comprehensive summary of the breakthroughs and milestones for these membranes is urgently needed to guide newcomers and inspire innovations in this field. The following chapters summarize the recent progress of 2D-material-based membranes for molecular separation, focusing on membrane preparation, characterization, and application. Chapter 2 introduces the fabrication methods for 2D materials and membranes. Chapter 3 presents the development of porous graphene-based nanosheet membranes. Chapters 4–6 describe the design and application of graphene-based membranes for water separation, ions separation, and pervaporation, respectively. Chapter 7 shows the development of 2D-material membranes for gas separation. Chapter 8 introduces the advance in 2D-LDHs membranes. Chapter 9 demonstrates the design of MXene and other emerging 2D-material membranes. Chapter 10 summarizes the milestones for 2D-material mixed-matrix membranes. Chapter 11 reveals the transport mechanism of 2D-material membranes. Finally, Chapter 12 gives the conclusions and perspectives of this research topic.

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