

PACS numbers: 72.80.Tm, 77.22.Ch, 77.22.Gm, 78.30.-j, 78.67.Sc, 81.07.Pr, 82.35.Np

Structural and A.C. Electrical Properties of Polyvinyl Alcohol/Iron Oxide Nanocomposites for Electronic and Electrical Applications

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The PVA–Fe₂O₃-nanocomposites' films were made using the casting method with various weight percentages 0, 2, 4, 6 of nanoparticles. When compared to pure PVA–Fe₂O₃ film, Fourier transform-based infrared (FTIR) spectroscopy spectra demonstrate a change in a peak location and, moreover, changes in terms of shape and intensity that suggests decoupling between the corresponding vibrations of iron-oxide nanoparticles (NPs). Images taken with optical microscopy reveal a distinct difference between the samples without and with iron-oxide NPs. When concentration reaches 6% weight, the iron-oxide nanoparticles create a continuous network inside the polymer. The dielectric characteristics of nanocomposites demonstrate that, as Fe₂O₃-NPs' concentrations rise, the dielectric constant, dielectric loss, and alternating-current electrical conductivity of PVA–Fe₂O₃ nanocomposites are increased. Additionally, when the frequency increases, the electrical conductivity of PVA–Fe₂O₃ nanocomposites increases, while their dielectric constant and dielectric loss fall. Based on these findings, nanostructures formed of PVA doped with Fe₂O₃ show themselves as promising materials for optoelectronic nanodevices due to improvements in structural and A.C. electrical properties.

Плівки нанокompatитів полівінілової спирт (ПВС)–Fe₂O₃ виготовляли методом лиття з різним ваговим вмістом наночастинок: 0, 2, 4, 6. У порівнянні з чистою плівкою ПВС–Fe₂O₃ спектри інфрачервоної спектроскопії на основі Фур'є-перетвору демонструють зміну розташування піку та, крім того, зміни форми та інтенсивності, що свідчить про розчеплення між відповідними коливаннями наночастинок оксиду Феруму. Зображення, одержані за допомогою оптичної мікроскопії, показують чітку різницю між зразками без і з наночастинками оксиду Фе-

руму. Коли концентрація сягає 6% ваги, наночастинки оксиду Феруму створюють безперервну мережу всередині полімеру. Діелектричні характеристики нанокомпозитів продемонстрували, що зі збільшенням концентрації наночастинок Fe_2O_3 зростають діелектрична проникність, діелектричні втрати й електропровідність змінного струму нанокомпозитів ПВС- Fe_2O_3 . Крім того, зі збільшенням частоти збільшується електропровідність нанокомпозитів ПВС- Fe_2O_3 , а їхні діелектрична проникність і діелектричні втрати падають. Виходячи з цих висновків, наноструктури, сформовані з ПВС, легovanого Fe_2O_3 , є перспективними матеріалами для оптоелектронних нанопристроїв завдяки поліпшенню структурних та електричних (для змінного струму) властивостей.

Key words: nanocomposites, structural properties, electrical properties, electronic applications.

Ключові слова: нанокомпозити, структурні властивості, електричні властивості, електронні застосування.

(Received 11 August, 2023; in revised form, 13 August, 2023)

1. INTRODUCTION

Investigation of polyvinyl alcohol (PVA) nanomaterials with iron oxide as well as of dispersing polymers with inorganic nanoparticles (NPs) has recently increased interest to improve various functional qualities; this includes electrical, magnetic, optical, thermal, and mechanical skills [1, 2]. Under preparation conditions, the composites' characteristics were impacted. Numerous studies have demonstrated the complexity of the creation and characterization of polymer composites, as well as the relationships between their processing, structural, morphological, and functional features [3, 4]. Due to its easy processing, high transmittance, and ease of solubilization in water, PVA is useful for a variety of polymer engineering technology, pharmaceutical, and biological applications [5, 6]. Because iron oxide nanoparticles are easily made in aqueous medium and are water soluble, the preparation is non-toxic. PVA has good qualities including thermal stability and chemical resistance, which have been thoroughly demonstrated by several investigations [7]. Iron-oxide nanoparticles have been discovered and become effective magnetic, magneto-optical, and electromagnetism platforms for medicinal applications [8, 9].

Researchers were interested in PVA/iron oxide polymer nanocomposites because of their improved properties and inexpensive production costs, making them the most attractive candidate among the competition after distributing Fe_2O_3 nanoparticles of PVA band gap [10–13]. The experimental findings that are currently accessible significantly improve our comprehension of their underlying ideas,

ensuring that this class of materials can be used in a wide range of applications. The optical characteristics of PVA nanocomposites, however, are receiving less attention despite recent advancements and developments [14, 15].

The optical properties can be used to provide detailed information because they are crucial and closely related to several other qualities. The quantity of iron oxide nanoparticles and the processes used to prepare the materials can have an impact on a number of significant Iron oxide nanocomposites without PVA optical characteristics, including band gap, reflection index, dielectric value, and optical absorption. For instance, varied magnetic properties for the same substance [16, 17]. Additionally, distinct magnetic, thermal, and electrical properties were discovered as a result of the dispersion particle concentration shift [18]. This result also reveals that the optical characteristics may be greatly affected by the effect of iron oxide concentration. Thus, it should come as no surprise that this topic is now undergoing extensive research and is still nascent. Therefore, the prospective application these nanocomposites can be controlled successfully by evaluating various synthesizing processes and analysing the connection between the qualities and the approach [19, 20]. In this study, nanocomposite films of PVA-Fe₂O₃ have not been thoroughly studied, and their properties have been investigated to improve their performance in various applications.

2. EXPERIMENTAL PART

The PVA-Fe₂O₃ blend with various Fe₂O₃ nanoparticle concentrations was used to create the nanocomposites. PVA was dissolved in 40 ml of distilled water at temperature 70°C, using a magnetic stirrer, to achieve more homogeneous solution. Fe₂O₃ nanoparticles were added with concentrations of 0, 2, 4, 6 wt.% by using casting method. An optical microscope of the Olympus type Nikon-73346 with a magnification of ×10 and a tiny photographic camera was used to test the materials at various concentrations. FTIR spectra have been investigated by FTIR. The range of wave numbers 500–4000 cm⁻¹ (Bruker, of Vertex-70 is of German origin. kind). Dielectric properties comprising dielectric constant, dielectric loss, and conductivity of an alternating current for the nanocomposites were tested employing the LCR-meter type (HIOKI 3532-50 LCR HI TESTER) for a range of frequencies between 100 Hz and 5 MHz.

The dielectric constant (ϵ') is given by [21] as follows:

$$\epsilon' = C_p/C_0, \quad (1)$$

where C_p is capacitance and C_0 is a vacuum capacitance.

The dielectric loss (ϵ'') is given by the following equation [22]:

$$\epsilon'' = \epsilon' D, \quad (2)$$

where D is the displacement.

A.C. electrical conductivity is determined by [23] as follows:

$$\sigma_{\text{A.C.}} = \omega \epsilon' \epsilon_0, \quad (3)$$

where ω is angular frequency.

3. RESULTS AND DISCUSSION

In order to study interactions between atoms or ions in nanocomposites of PVA- Fe_2O_3 , changes in the vibrational modes of these interactions can include the nanocomposites. The transmittance spectra of FTIR for PVA- Fe_2O_3 nanocomposites are shown in Fig. 1, *a*, *b*, *c*, and *d*, reported in the range of $600\text{--}4500\text{ cm}^{-1}$ at standard room temperature. It is obvious from the infrared spectra that vari-

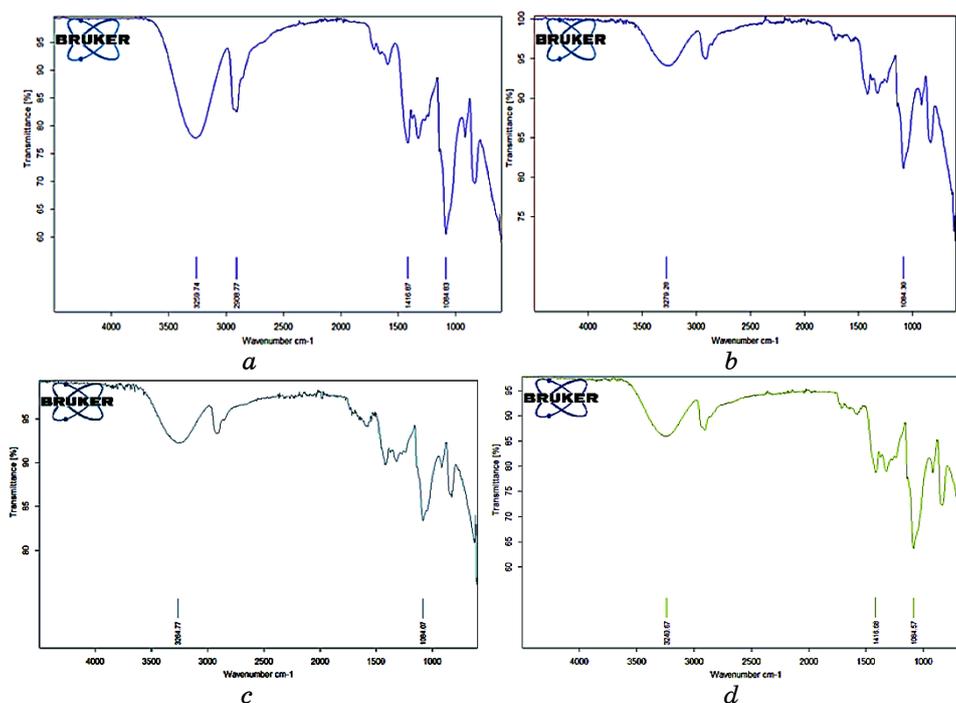


Fig. 1. FTIR spectra for PVA- Fe_2O_3 with nanocomposites: (a) PVA; (b) 2 wt.% Fe_2O_3 NPs; (c) 4 wt.% Fe_2O_3 NPs; (d) 6 wt.% Fe_2O_3 NPs.

ations in the ratio of Fe₂O₃ nanoparticles result in some discernible the spectrum of PVA changes. It causes certain new zones of absorption to form as well as small adjustments to the intensities of some existing bands. Similar to flaws caused *via* means of charge-transfer interaction in the space between the dopant species and a polymer chain, the new absorption bands may be connected. The PVA films' FTIR spectra showed broad and powerful frequencies at 3750 cm⁻¹, which is attributable to the O-H groups of hydroxyl vibrating during the stretch, and at 2921 cm⁻¹, which is attributed to the O-H vibration breaking of the hydroxyl molecules, which is attributed to the C-H shaking and stretching. The C=O, C=C elongating modes are thought to be responsible for peaks at 1558 cm⁻¹ and 1457 cm⁻¹. FTIR spectra show decrease in the transmittance with increasing ratio of nanoparticles [24, 25].

Figure 2 shows images of films made of PVA-Fe₂O₃ nanocomposites, which were captured at ×10 magnification for samples with different concentrations. This figure manifests clear differences between image *a* and images (*b*, *c*, *d*). When the concentration of iron-

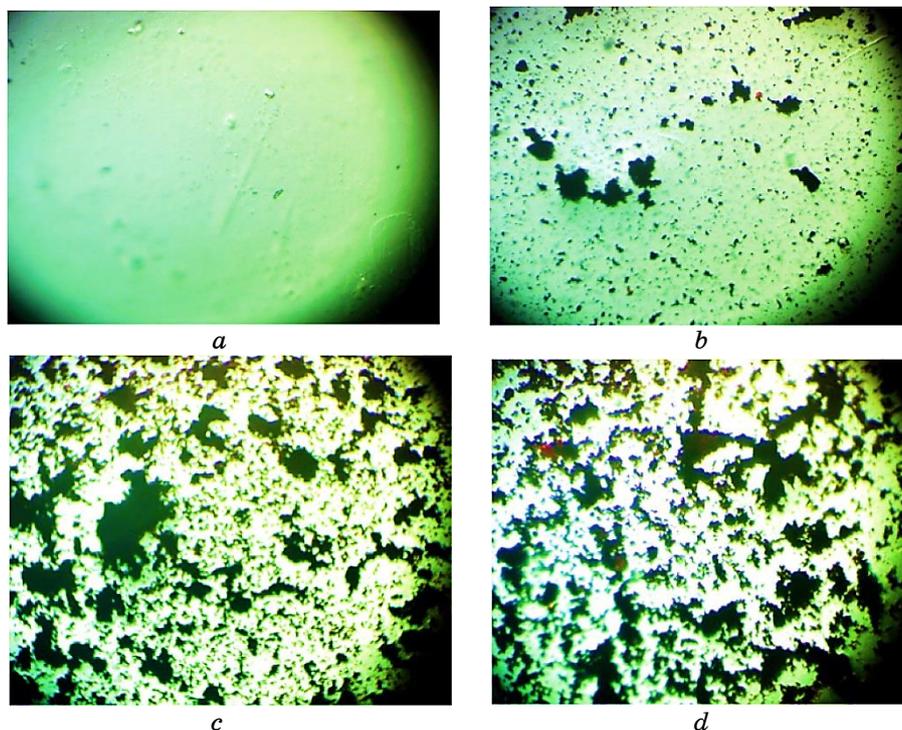


Fig. 2. Photomicrographs (×10) for nanocomposites of PVA-Fe₂O₃: (a) PVA; (b) 2 wt.% Fe₂O₃ NPs; (c) 4 wt.% Fe₂O₃ NPs; (d) 6 wt.% Fe₂O₃ NPs.

oxide nanoparticles reaches 6 wt.%, the nanoparticles form a continuous network inside the polymer. Charge carriers are allowed to move along certain channels in this network, which reduces the resistance of the polymeric material (PVA) [26, 27].

Figure 3 depicts the dielectric constant with frequency for PVA–

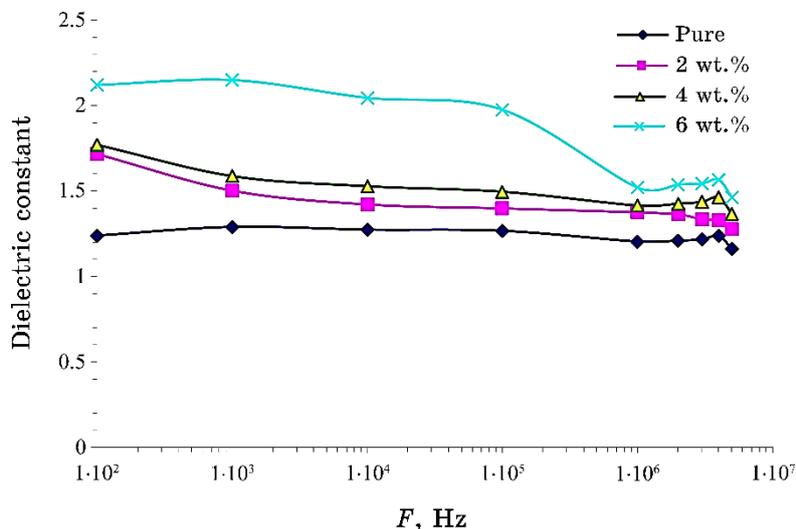


Fig. 3. Variation of the dielectric constant with frequency for PVA–Fe₂O₃ nanocomposites.

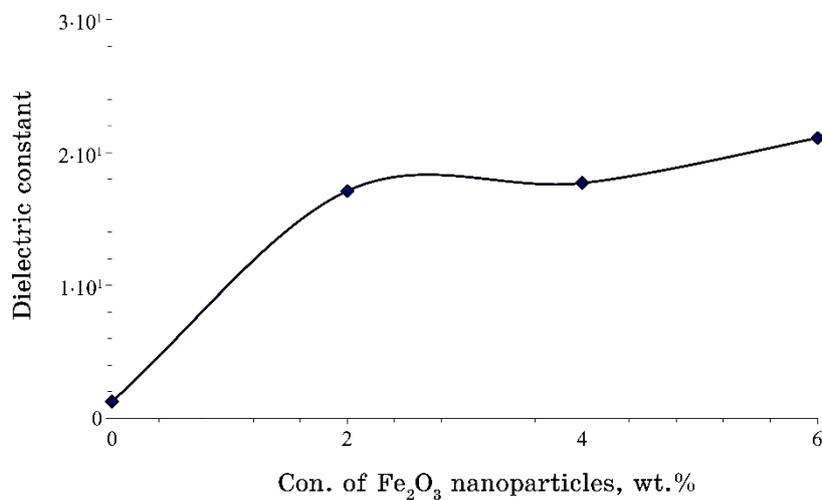


Fig. 4. Change of the dielectric constant for PVA–Fe₂O₃ nanocomposites with iron-oxide content at 100 Hz.

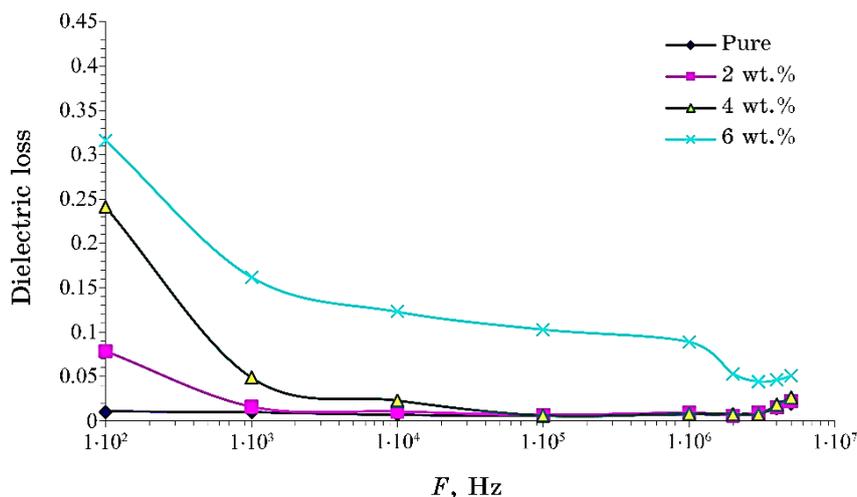


Fig. 5. The dielectric loss as a function of frequency for PVA–Fe₂O₃ nanocomposites.

Fe₂O₃ nanocomposites. The figure demonstrates that, as frequency increases, the dielectric constant falls that is due to a reduction in space charge polarization [28–30]. Additionally, as shown in Fig. 4, we can see that the dielectric constant rises as the concentration of iron-oxide nanoparticles raises that is because of an increase in the charge carried by the nanoparticles [31–34].

Figure 5 depicts the influence of frequency on the dielectric loss of PVA–Fe₂O₃ nanocomposites at various iron-oxide-nanoparticles' concentrations (see Fig. 6 too). Because there are fewer dipoles in nanocomposites, the dielectric loss lowers as frequency rises [35–38].

As shown in Fig. 7, the polymer-matrix electrical conductivity increases with an increase in weight percentage of iron-oxide nanoparticles. This is a result of an increase in the quantity of electrons in nanocomposites [39, 40]. A.C. electrical conductivity of PVA–Fe₂O₃ nanocomposites is increasing with frequency too (Fig. 8). Due to electronic polarization and transporters of charges, which move by hopping, the conductivity of alternating current (A.C.) increases as frequency rises [41–43]. According to Fig. 8, a rise in iron-oxide nanoparticles' concentration leads to an increase in electrical conductivity of nanocomposites, which is attributable to an increase in charge carries [44, 45].

4. CONCLUSIONS

1. The FTIR spectrum shows a difference in peak position and in-

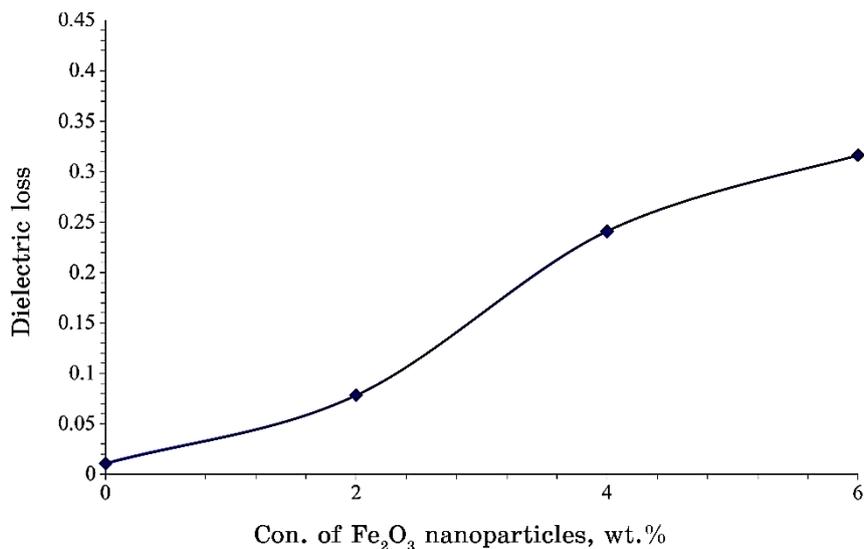


Fig. 6. The dielectric loss for PVA-Fe₂O₃ nanocomposites varying with iron-oxide nanoparticles' content at 100 Hz.

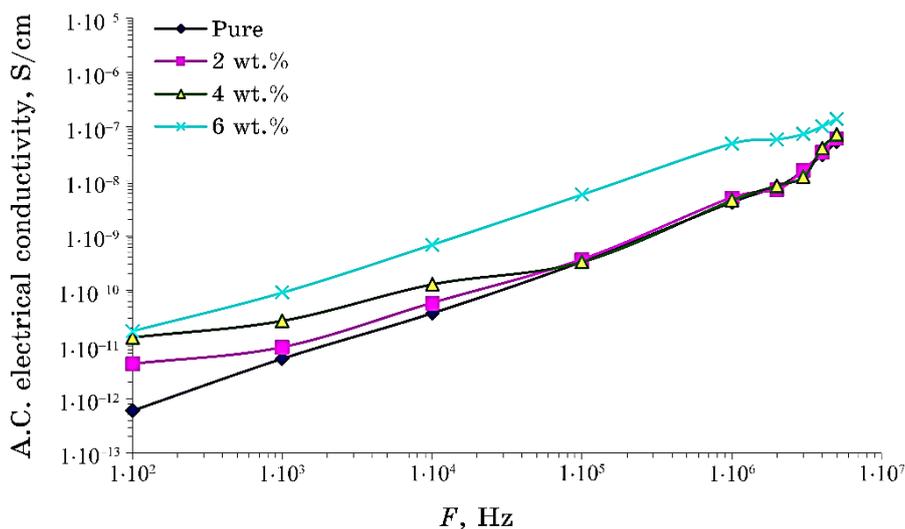


Fig. 7. The A.C. electric conductivity of PVA-Fe₂O₃ nanocomposites varying with frequency.

tensity of PVA-Fe₂O₃ nanostructures. This suggests the disassociation between the vibrations in the polymer and the iron-oxide nanoparticles.

2. From optical-microscopy images, the iron-oxide nanoparticles

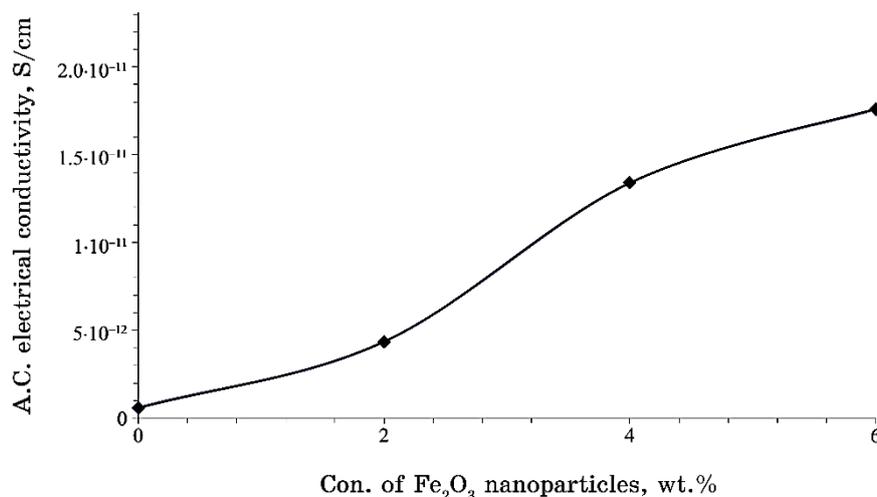


Fig. 8. A.C. electrical conductivity of PVA–Fe₂O₃ nanocomposites *versus* iron-oxide nanoparticles at 100 Hz.

form a continuous network within the polymer (at concentration 6 wt.%).

3. As the frequency rises, the dielectric constant and dielectric loss decrease, while A.C. electrical conductivity increases for all PVA–Fe₂O₃ nanocomposites.

4. The dielectric constant, dielectric loss and electrical conductivity are increasing with increasing of Fe₂O₃ nanoparticles.

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